DISCOVERY

THE PROGRESS OF SCIENCE

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DISCOVERY

THE MAGAZINE OF SCIENTIFIC PROGRESS

Editor WILLIAM E. DICK, *B.Sc, F.L.S.* *Editorial Office* 244 High Holborn, WC1 Chancery 6518
Subscription, distribution and business communications to Jarrold & Sons Ltd, Norwich Norwich 25261
ADVERTISEMENT OFFICE Aldridge Press Ltd. 27 Chancery Lane, WC2 Holborn 8655

SEPTEMBER 1955 VOLUME XVI NUMBER 9

THE PROGRESS OF SCIENCE

SCIENTIFIC PROPHECIES

The advance of science and technology is now so rapid that most scientists hesitate to speculate about the shape of things to come, in say, twenty or fifty years. They feel safer if asked to predict what may materialise in the way of scientific and technological developments in the next ten years, for it is then possible to take present trends that are becoming clear and obvious and extrapolate from them: ten-year forecasts tend to be the obvious trends writ large, so to speak. Those who are prepared to publish their speculations of what will be happening in 1975, or 2005, have to be much bolder, and they deserve applause for both courage and imagination One interesting article in this genre by Sir Francis Simon of the Clarendon Laboratory can be read in the *Financial Times* annual review of British Industry. He looks twenty years into the future, and considers such matters as the potentialities of atomic energy. This cannot revolutionise road transport, he says, though it can affect the railways insofar as the advent of nuclear power can favour the speedier electrification of rail transport. Atomic piles are not of immediate use for road transport, and Sir Francis says that the same thing applies to air transport. Most experts will agree with the first prediction and probably atomic-powered aircraft will not materialise for quite a few years in spite of all the talk about this idea. About atom-powered ships Sir Francis has no reservations: "Atomic Energy will certainly be used at sea, mainly for big liners." He then refers to Sir George Thomson's suggestion about the possibility of fast transport by large submarine liners, which would be much more efficient hydrodynamically than surface transport. "Hitherto such liners could not be considered, because the conventional fuels demand an ample supply of oxygen, but now there is the possibility of nuclear plant. Sir George foresees submarine liners travelling at over twice the speed of the present surface liners and at less cost. This would, of course, be of very great importance for transporting bulk materials and might even attract passenger traffic." (This, we understand is one of the predictions which Sir George makes in his book *The Foreseeable Future* to be published sometime this autumn.)

Sir Francis rejects the idea that atomic space ships will soon be forthcoming. He comments: "What is *not* going to happen in the next decades, in spite of all the science fiction, is interplanetary flight by manned space ships. In particular nuclear energy, on which most fiction 'scientists' rely, is not a particularly suitable source for this purpose."

This article, which is entitled "The Next Twenty Years", discusses quite a number of points besides the importance of nuclear power. The kind of progress which he visualises can only occur, of course, if we have a sufficiency of scientists and technologists, and Sir Francis regards Britain as unprepared for the future in this respect. He thinks more should be done to switch higher education from the arts side, where we have over-production, to the science side where we are desperately short of men. He then says: "Science is still the stepchild, at least in this country. Very far-reaching changes in our way of life are needed, but it seems that we are all occupying back seats, busy in our own little corner, while nobody is at the wheel. The question which will first cause serious worries to industry is that of scientific and technological manpower. Twice the present output of first-rate men could easily be taken up. The position has been aggravated by the fact that American firms have taken to using this country as one of their hunting grounds, and the latest development is that American firms are flying British graduates over for interviews in the United States! Apart from industry, the universities and Government departments are also competing—while the needs of the schools must not be forgotten. The position is going to deteriorate fast and the question of getting their share of manpower and making the best use of it is vital to every firm."

Another scientist who has taken a far-sighted view

of the future developments that may emerge from current work is Dr. John von Neumann, who is now a member of the U.S. Atomic Energy Commission, writing in the June 1955 issue of *Fortune*. After talking about automation and nuclear energy, he puts forward some very novel ideas about how man might control the climate. Here he goes far beyond such things as artificial rain-making. He speculates about the possibility of raising the temperature by, say, 15° when the ice of Antarctica would melt and the climate all over the world would become tropical to semi-tropical. The reason why large ice-fields persist is that ice both reflects sunlight energy and radiates terrestrial energy at a higher rate than ordinary soil. Von Neumann considers that it is well within the range of man's ingenuity to alter both the reflection and radiation to his advantage. He visualises that microscopically thin layers of coloured matter could be spread on the icy surface (or in the atmosphere above it, though here he gives no details of what he has in mind) to inhibit the reflection-radiation process, with the result that the ice would melt and the local climate would be changed. Von Neumann says: "Measures that would affect such changes are technically possible, and the amount of investment required would be only of the order of magnitude that sufficed to develop rail systems and other major industries." As in the case of rain-making experiments not everyone would be happy with the results that would come from such a project. As Von Neumann puts it, what could be done is no index to what should be done: to make a new tropical age is not necessarily a rational programme. He goes on to say that to evaluate the ultimate consequences of either a general cooling or a general heating would be a complex matter. But one rather gathers that Von Neumann would himself revel in the unravelling of that complex nexus of various factors using electronic computers in the ingenious kind of way that such instruments are already being used to unravel the complexities of the weather for purposes of long-range forecasting. His concluding comment on climate control is a marvel of understatement: "What power over our environment, over all nature, is implied."

One cannot help noticing that such predictions always carry with them a enpeptic feeling of optimism: it is left to the novelists to think about the ways man may abuse the new ways of gaining additional power over nature which the scientists can invent and the engineer may put into practice. Optimism is the keynote of a new book entitled *The Road to Abundance* by Jacob Rosin and Max Eastman (English edition by Rider & Co., 1955, 12*s.* 6*d.*; originally published by McGraw-Hill, New York), largely concentrates on the problem of feeding the world's ever-increasing population and solves it by the development of factory processes for synthesizing food. The aim of this book is to show that modern science, with chemistry in the lead, can create an absolute abundance of food, fibres and industrial commodities without relying on fields and mines. It is a stimulating and very provocative work, and can be strongly recommended as an imaginative piece of writing. It puts forward various proposals which seem at first sight very remote from modern reality. There is a grain of practical feasibility in many of them, though others are extravagant extrapolations from a rather small modicum of established fact.

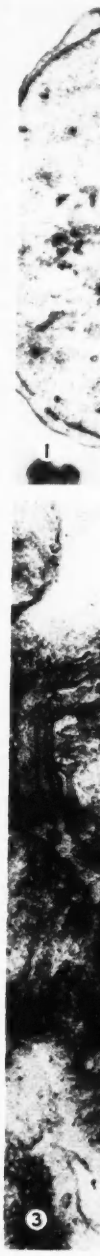
CUTTING SECTIONS THROUGH VIRUS PARTICLES

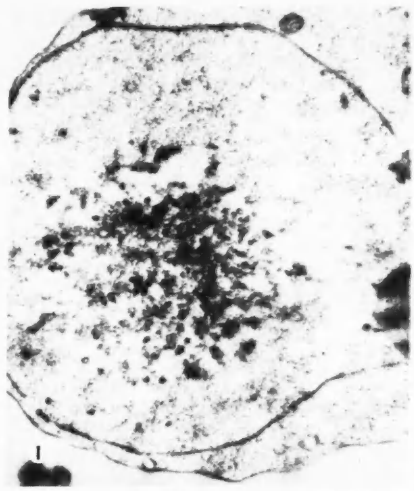
The effects of the invention and development of the electron microscope on various aspects of biological study are far-reaching. For example, before the advent of the electron microscope, no one had ever seen a virus. Most animal, and all known plant, viruses are in fact beyond the resolving power of the optical microscope. Now, however, quite a number of plant and animal viruses have been photographed, and their size and shape are accurately known. They have even been cut in sections.

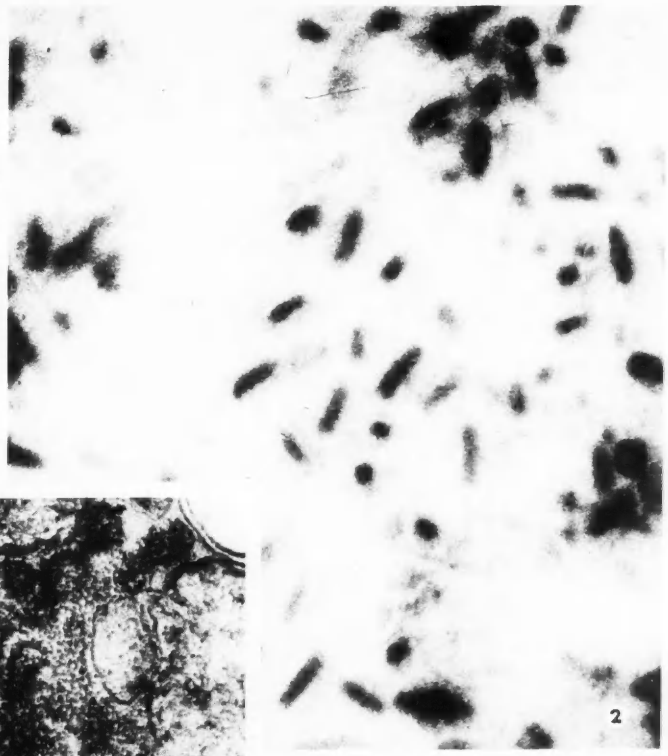
Recent developments in technique have greatly widened the scope of electron microscopy in its biological applications. This is particularly true of the improved method of cutting ultra-thin sections. Briefly, this consists in fixing the object in buffered osmic acid, and embedding in a transparent plastic (either methyl or butyl methacrylate); this is polymerised and then cut on a special microtome.

Although the process is essentially similar to the well-known method of embedding in wax and sectioning which biologists have been using for many years, there are certain differences. For example a glass knife is preferable to the conventional steel knife, and this is prepared by scoring and fracturing a piece of plate glass at an angle of 45°. The sharpness of the knife-edge is one of the critical factors. Another is the advance mechanism whereby the object approaches the knife-edge; this is usually accomplished by thermal expansion, either by means of an electric current or the heat of a lamp. As the sections are cut, they are floated off the knife-edge on to the surface of acetone or alcohol contained in a metal bath round the knife-edge. The sections are then lifted off the liquid by inserting underneath them the grids which fit into the object-holder of the electron microscope. By using specially made grids with slots it is now possible to prepare serial sections. With these ultra-thin sections it is preferable not to remove the plastic embedding medium, since the use of a solvent for this purpose is liable both to distort the cell contents and to produce artefacts

So far as the study of viruses is concerned the most exciting application of the new technique is to try to follow the behaviour of viruses inside the cell. It is specially suitable in the case of certain virus diseases of insects where the virus is known to develop and multiply inside the nucleus of the cell. The larva of the crane fly (*Tipula paludosa*) is subject to a virus which attacks the blood cells and causes a kind of leukaemia. In Fig. 1 can be seen an ultra-thin section of part of such a diseased blood cell. In the centre of the nucleus (which has enlarged to fill most of the cell), can be seen







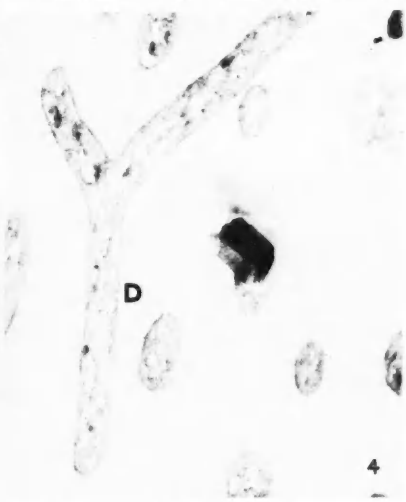


FIG. 1. Thin section through a diseased blood cell of a crane-fly larva; note how the nucleus has enlarged until it almost fills the cell. The dark spots in the centre are the developing virus particles. Magnification, ×16,000.
FIG. 2. Virus particles seen in section; note how each particle is surrounded by a membrane. Magnification, ×50,000. (The sections shown in these two photomicrographs are between 300 and 500 Angstroms thick—or about a thousand times thinner than an ordinary microscope section.)
FIG. 3. Longitudinal section through the salivary gland of *Chironomus*. Magnification, ×75,000.
(*Courtesy, Dr. J. R. G. Bradfield.*)
FIG. 4. Section through *Mycobacterium phlei*; note the division (D) developing on the left. Magnification, ×20,000.
(*Courtesy, A. M. Glavert and Dr. E. M. Brieger.*)

a condensation of darker spots which are the developing virus particles, and these can be separated from the surrounding cellular material by high-speed centrifugation. In Fig. 2 are shown sections of the actual virus particles isolated in this way. Note the rod-like shape of the virus particle, the surrounding membrane, and the apparently granular nature of the virus material itself.

There are, of course, many other applications of this technique besides the study of viruses. In Fig. 3 is shown a longitudinal section of the salivary gland of *Chironomus*. It passes through the outer 3–4 microns of cytoplasm which is rich in tracheoles (empty circles) and mitochondria The latter show conspicuous double membranes (sometimes transverse, sometimes longitudinal, often branched) but also contain irregular circles or ellipses which may be tubes or granules in transverse section.

By studying thin sections of bacteria and other organisms much knowledge may be gained of their internal structure. Fig. 4 is a section of *Mycobacterium phlei*, and in it may be seen details of division and a number of light areas which are possibly the nuclear apparatus.

Another line of work is the study of the plant cell, and some very fine pictures have been taken of the submicroscopic structure of chloroplasts which appear to be laminated.

The new section-cutting technique is likely to have very wide applications in the biological field, but, as always, these advances in technique bring difficulties in their train. For example, the sections may now be so thin that they are actually thinner than the collodion film on the grid on which they rest. This leads to resolution difficulties in the electron microscope, so that a new supporting film made of carbon, much thinner than the films used previously, is being tested.

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BOUNDARY LAYER CONTROL

Associated with the jet engine which has given us so much greater speed in the air are new developments that will make it possible to reduce the take-off and landing speed of aircraft. This speed reduction is being approached in several ways. Recently we published a "Progress of Science" note about the development of vertical take-off aircraft, and another about the experiments with jet deflection. (These notes appeared in September 1954 and April 1955 respectively.)

A third method makes use of what aeronautical experts call *Boundary Layer Control*. Practical, fast-flying military aircraft are now beginning to appear equipped with boundary layer control devices. It is interesting to note that the first aeroplanes to have them are naval machines. The advantages of lower speeds for take-off and landing in aircraft carriers are obvious. But one of the foremost experts on the subject of controlling the boundary layer, Dr. G. V. Lachmann, Director of Research in the Handley-Page concern, says that low landing and take-off speeds, unprecedented fuel economy in cruising flight and substantial extensions of range of jet airliners or military transport aircraft are now possible through control of the boundary layer next to an aircraft's surface. (Dr. Lachmann's paper delivered to the Royal Aeronautical Society on November 11, 1954, is a useful survey of boundary layer control.)

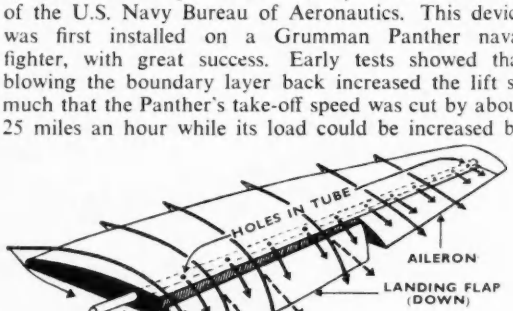
The principles of the boundary layer have been known to aerodynamicists for the last fifty years, practically as long as man has been flying aeroplanes, but the development of the modern powerful jet engine has made it possible to introduce better control of the invisible layer of air as it flows off the surface of the wings.

This boundary layer lies, as an aircraft flies through the air, between the extremely thin "film" of air which remains stationary because of friction, and the free air stream. As it flows over the wing the boundary layer thickens and becomes turbulent, causing drag. Farther back along the wing the airflow separates causing eddies and loss of lift.

Efforts to overcome this have been made by what aerodynamicists colloquially call "sucking and blowing". The boundary layer is sucked over the flaps through slots near the leading edge, or it can be blown over the flaps from a slot just ahead of the flaps. Many experiments have been made with suction both here and abroad over many years.

Germany developed a combined sucking and blowing system during the war, and post-war tests of this device in America reduced the stalling speed of a small piston-engined aeroplane by more than 11 m.p.h. and the take-off distance by 40%.

The latest boundary layer equipment, however, achieves its effect by blowing only, using air "bled" from the compressors of the gas-turbine engine. This system was developed in America by John S. Attinello, of the U.S. Navy Bureau of Aeronautics. This device was first installed on a Grumman Panther naval fighter, with great success. Early tests showed that blowing the boundary layer back increased the lift so much that the Panther's take-off speed was cut by about 25 miles an hour while its load could be increased by



The Attinello device in which the use of compressed air from the jet engine results in increased lifting power on the wing. The broken arrows indicate air flow with conventional wing; the heavy arrows indicate direction of freed air flow produced by the Attinello device.

3000 lb. It is a simple device. A tube goes through the wing slightly ahead of the flaps, and holes are spaced out along the tube's length, and through them compressed air from the engine is blown out, forcing the boundary layer right over the wing instead of separating away as it would otherwise do. The Attinello "blower", which greatly improves controllability of the aeroplane at low speeds and delays the stalling point, is now being standardised in the Lockheed T2V–1 two-seater jet trainer for the United States Navy, and it is believed that the designers of the first American jet-propelled airliners will incorporate the equipment in their machines. Developed from the earlier Shooting Star fighter, the new trainer flies at 600 m.p.h., but with the "blower" lands at only 97 m.p.h.

Britain is making use of the Attinello "blower" too. It was revealed this July that the Vickers-Armstrong Supermarine 525 was equipped with what is called "supercirculation". This was the first British aircraft to have a boundary layer "blower". Unfortunately this prototype aircraft was destroyed on a test flight from Boscombe Down. It was the well-tested forerunner of a new twin-jet fighter that is being developed for the aircraft carriers of the Royal Navy, the N.113. Presumably when they are ready for service the N.113's will have the boundary layer control device. British designers are also turning their thoughts towards the use of boundary layer control on large aircraft.

THE MYCOLOGICAL INSTITUTE'S NEW LABORATORIES

In July the Duke of Edinburgh opened the new laboratory block of the Commonwealth Mycological Institute at Kew. In the twenty-five years of its existence the Institute has twice outgrown its accommodation. At its foundation, under the name of the Imperial Bureau of Mycology, it was housed in two cottages on Kew Green; in 1930, as the Imperial Mycological Institute, it moved into a new building in Ferry Lane, but in seven years this, too, had become too small for the increasing staff and activities.

The new building provides accommodation for the extensive library and for all laboratory operations. Georgian in style, it harmonises with the neighbouring buildings. Internally, its equipment and finish are modern. The photographic rooms in the basement are designed to suit a variety of special techniques, including microfilm and microcard processing and the preparation of offset foils used in the production of publications from electric typewriter originals. The basement space is protected by a bituminous tank designed to prevent damage by river floods such as occurred in 1953. Most of the ground floor is occupied by the library. The first floor houses the large fungus herbarium, and the accessory laboratories and fumigation plant. On the second floor there are four rooms for visiting workers from overseas, and the laboratory of the culture collection.

During the 1914–18 war, concentration on the major problem of feeding the nation revealed the dangerous extent of losses of food crops and essential raw vegetable materials caused by diseases, the agents of which were mainly fungi. The task of collecting and disseminating information on these diseases and their control was entrusted to the new Imperial Bureau of Mycology, the first Director being Dr. (later Sir) Edwin Butler. The functions of the Bureau were, briefly, to supply information on crop diseases due to fungi through the medium of the *Review of Applied Mycology*, a monthly abstract journal; to advise overseas governments and agricultural departments; and to assist colonial pathologists in the identification of the fungi they encountered. Since those early days many other publications have been produced, including reference books, monographs, a *Review of Medical and Veterinary Mycology*, the *Index of Fungi* (which records new species and new names), maps showing the world distribution of important crop diseases, and the *Catalogue of the Culture Collection*.

THE DUKE of EDINBURGH at KEW.

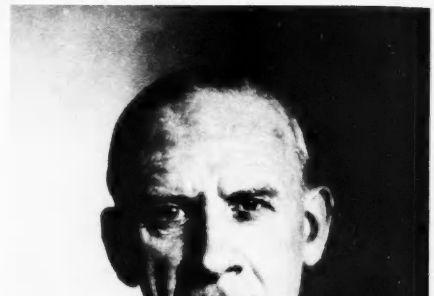
The identification of the micro-fungi is a difficult task, calling for considerable experience, and access to a very extensive literature and collections of preserved material. Since 1920, E. W. Mason, the Chief Mycologist (who was awarded the O.B.E. in the last Birthday Honours), has built up a fine fungus herbarium which is very efficiently organised and documented, and comprises some sixty thousand collections from all parts of the world.

The culture collection is in part a living extension of the herbarium, storing and issuing cultures of taxonomic significance needed for research by the Institute staff and by outside workers. Cultures are also supplied to schools and universities for teaching purposes, and to firms operating microbiological processes. The collection, which at present comprises over two thousand isolations, is in the charge of H A. Dade, the Assistant Director.

Since 1939 the Director has been Dr. S. P. Wiltshire, who heads a staff of thirty-seven, of whom ten are mycologists. A recent innovation is the recruitment of a pool of experienced pathologists who are based on the Institute and who can be sent in an emergency to any Commonwealth country to investigate without delay any new and potentially disastrous outbreaks of crop diseases. One example illustrating the value of this new development: R. A. Alston, the senior Pool Pathologist, recently discovered the cause of a troublesome disease of broad beans, a staple food crop in Cyprus, and has introduced new varieties of this plant which seem to be resistant to the parasitic fungus.

SCIENCE AND THE SCIENTIST

PROF. SIR ROBERT ROBINSON
O.M., F.R.S.



This week the British Association is holding its 117th Annual Meeting in Bristol. The opening ceremony on August 31 was held in the Colston Hall, and afterwards Sir Robert Robinson delivered his presidential address, the full text of which is printed here.

The Association held its sixth Annual Meeting in Bristol in August 1836 under the Presidency of the Marquis of Lansdowne. No significance need be attached to the fact that the well-known riots occurred here in the following year which is much better dated by the accession of Queen Victoria. I noted from the Report with interest and a certain wistful approval that the Address was delivered on that occasion not by the President but by Charles Daubeny, Fellow of Magdalen College, Oxford, Local Treasurer for Oxford. Daubeny had already been appointed to the University Chairs of Chemistry and of Botany. He was well qualified to profess Geology also, but his eventual third Chair was that of Rural Economy. He was a founder member of the Association and had attended the five previous meetings. Undoubtedly one of the chief pioneers and benefactors of science in Oxford he was a man of great originality and tireless energy. Among many notable contributions to knowledge, one that deserves the epithet classical was his discovery that the process of photo-synthesis occurred more rapidly under the influence of blue and violet light than under that of the less refrangible rays.

In the course of his Address, Daubeny referred, among other things, to various systems of notation in chemistry and mentioned in that connexion Dr. John Dalton, whom he described as the "venerable" founder of the Atomic Theory but who was in fact just short of seventy years of age. At the meeting of the Association in the previous year at Dublin Dalton had given an account of his experiments on the distillation of caoutchouc and of the formation of a volatile oil which was doubtless crude isoprene. This he called "double olefiant". One volume of the vaporised substance exploded with six volumes of oxygen gave four volumes of carbonic acid gas which works out for:

$$C_5H_8+6O_2=4CO_2+3H_2O+(CH_2O)$$

Here the CH_2O merely represents loss of partly oxidised hydrocarbon. I mention this matter, rather out of context, because the work seems to have been forgotten.

Dalton was not too "venerable" either to be a Vice-President of the Chemistry Section at the Bristol Meeting or to be charged with the duty of examining the lesser constituents of the atmosphere. One wonders whether the small incombustible residue noted by Cavendish, and which was undoubtedly argon, was known to him.

The next meeting at Bristol was in 1875. The President was the eminent engineer, Sir John Hawkshaw, and he delivered a most interesting address on the historical development of achievement made possible by applications of engineering and other sciences. The last three sentences will interest you. ". . . Need we try to extend our vision into futurity further? Our present knowledge, compared to what is unknown, even in physics, is infinitesimal. We may never discover a new force—yet, who can tell?"

The meeting was attended by many famous men of science and among the Officers of Sectional Committees we find Cayley, Thomson (afterwards Lord Kelvin), Tyndall, Rayleigh, Williamson, Galton, Armstrong and Tilden; a short list at random that could be greatly extended.

Sir William Crookes was the President at the third Bristol meeting in 1898 and he delivered an outstanding address on a variety of topics. First on the gloomy prospects for the supply of bread to the people of these islands. Here he foresaw with characteristic intuitive genius that the only possible solution would be to obtain nitrogenous products from the atmosphere. At that time the only known method was the combustion of nitrogen with the help of a powerful electric discharge, an experiment initiated by Henry Cavendish, developed by Crookes himself in 1892, and by Rayleigh for the isolation of argon. Crookes even calculated that electricity generated from coal could be used to produce sodium nitrate at £26 per ton and that power from Niagara would reduce the cost to £5 per ton. The figure for Chilean nitrate was £7 10*s*. per ton, estimates which have only relative interest at the present time. If the Haber synthetic ammonia process had not offered a much better alternative, it is possible that Crookes's idea would have been commercially developed. In any case his thoughts were along the right lines.

Crookes was able to report that on May 10, 1875, Dewar had written to him: "This evening I have succeeded in liquefying both hydrogen and helium." Further, he mentioned that in the preceding few months, Ramsay and Travers (a distinguished Bristolian) had discovered three new rare gases of the atmosphere.

He goes on to speak of x-rays and the early discoveries of radioactivity by the

Curies and Becquerel. Speculating on the source of the energy unceasingly radiated he found it in the translational motion of the molecules, and of the atoms within the molecules. He was thus led to the considerable underestimate that the air in a room of moderate size "contains energy enough to propel a one-horse engine for more than twelve hours", and continues, "The store drawn upon naturally by uranium and other heavy atoms only awaits the touch of the magic wand of Science to enable the Twentieth Century to cast into the shade the marvels of the Nineteenth." How much more true that is than Sir William Crookes imagined.

His final section on psychical research and experimental psychology was restrained but confident. He was conscious of the criticism which he was inviting but did not shrink from giving witness to his conviction that the phenomenon of telepathy, for example, was a real one and that the subject should be studied by scientists.

May I now interpolate that we should all agree with this. Telepathy, and even pre-cognition, are claimed to have been established and surely it is extremely important to know whether the evidence is really good enough to justify these claims. In the first place we need to discuss how to set to work, and only when that is quite clear to put a plan into operation. It is the first stage which is likely to be the more difficult. Perhaps it should be added that no final verdict can be anticipated. As our distinguished colleague Dr. Warren Weaver has so aptly remarked, there is no such thing as the voice of science.

End of the Darwinian Epoch

The last Bristol meeting was in 1930 with Prof. F. O. Bower as President. He spoke on "Size and Form in Plants" and remarked that this ninety-ninth year of the life of the Association marked the close of the Darwinian epoch. That was intended only in relation to personal links and did not imply that Darwin's influence on science had in any way lessened. Bower naturally referred to Sir William Crookes's remarkable address of 1898 and was able to point not only to the actual production of artificial fertilisers, but also to the development of new strains of wheat which enabled areas of lower rainfall to be utilised, and also shortened the period between sowing and reaping.

So far, in asking for your attention to the reverberations of the thunder of the past, I have been on solid ground but now the situation changes as I turn to my own choice of a topic. I recall the case of the Texas politician who was said, naturally by an opponent, to have "both feet firmly planted in the air". However, even if this is thought to apply, I hope to come to earth occasionally.

One of the troubles of the modern life of scientists is that we are all too busy and that only a small fraction of our available time and energy can be spent in practising our real vocation. Please forgive a personal reference—it is not really very boastful. I am conscious of a certain talent for tapping a test-tube but it is a long time since I was able to indulge this bent to much purpose. Lately I have had to be content to encourage others to perform this simple operation with, it should be added, due consideration of what is placed in the test-tube, and observation of what happens.

When the Secretary asked me for the title of this Address, I was more than usually preoccupied and selected "Science and the Scientist" because I thought it clay that could be modelled into almost any desired shape.

However, there was at the back of my mind the feeling that the functions of the two are not always clearly understood and distinguished, so that there is more than a little confusion of thought in some quarters, especially in the use of the word "Science". The subject is not at all controversial but I will ask for your indulgence to state once more the generally accepted definition, clearly implied in common consent if not the subject of any recent manifesto.

Science is simply the record, enshrined in the literature, of the system of knowledge and of the conceptions correlating parts of that system.

It is fundamental that such knowledge cannot be based on dogma or authority of any kind, nor on any intuition or revelation, unless indeed it be of the Book of Nature that lies open before our eyes. We need not dwell on the processes of acquiring knowledge by observation, experiment, and inductive and deductive reasoning. The study of scientific method both in theory and practice is of great importance but this topic requires separate treatment. Further it is inherent in the philosophy that the record may be imperfect and the conceptions erroneous; the potential fallibility of our science is not only acknowledged but insisted upon.

Successive Approximations to the Truth

Still there are degrees of uncertainty and even the apparent revolution in physics that has occurred in the twentieth century has not so much superseded the older teaching as supplemented and extended it by wider generalisation.

The improvement of knowledge by successive approximations is fundamental and it is worth while to consider some illustrations.

A very simple example of the improvement of a nearly true statement of a relation is that of the Boyle-Charles Law. This stated that the volume of a gas is directly proportional to the temperature and inversely proportional to the pressure. It can be expressed as $pv = RT$. This works very well for most practical purposes but it is not quite correct, especially at higher pressures. In 1873 van der Waals pointed out that the volume (v) taken should be lessened by a quantity (b) related (but not equal to) the volume of the molecules themselves, i.e. $v-b$ for v. The pressure (p) should be increased by a quantity $\frac{a}{v^2}$ which denotes the cohesion of the molecules.

With the expression,

$$\left(p+\frac{a}{v^2}\right)(v-b) = RT,$$

a much better agreement with the experimental data was obtained but it was still not absolutely accurate and more or less successful modifications have been suggested.

The "ideal" gas which obeys the Boyle-Charles law may perhaps be compared to the "ideal" railway that conforms to Bradshaw. The divergence from the ideal in the performance of a railway becomes greater when the traffic is congested and this factor is not unlike the b of van der Waals. But railways are much worse than gases, chiefly due to the appearance of the human factor, which is quite incalculable.

Molecular Structures

Where the material can be directly apprehended by our senses, aided perhaps by devices such as cameras, microscopes and telescopes, there can be little doubt as to the validity of the record, though it may need some adjustment of errors of observation and of the value of any magnitude that is involved. The uncertainties are then largely concentrated on the conceptions and generalisations which have been based on the ascertained facts. May I be excused if I refer to the subject I know best in illustration. The molecular structures of the chemist are not directly perceptible but must be deduced from observations on collections of very large numbers of molecules, and yet a most remarkable system has been evolved which even forms the conventional basis of patents and is recognised as valid in courts of law. The degree of uncertainty is indeed not much increased by the fact that we cannot see these structures.

Leaving aside philosophical dubieties about reality we can say that the limits of our knowledge in this field are somewhat as follows. That the atoms exist as entities, but the problem of the nature and constitution of the atoms themselves has not been fully solved; rapid progress is being made. We know the arrangement of the atoms in the vast majority of the species of molecules which we find in Nature and we have learned how to construct molecules, even those of a highly complex pattern. The defences of some of the last strongholds are in process of being breached.

A brilliant example of modern work of this kind will be described by the President of Section B (Chemistry), Sir Alexander Todd. It concerns the structure and synthesis of the nucleosides, those vastly important constituents of the nuclei of living cells. Even the proteins are being forced to reveal their secrets and though none of them has yet been synthesised we have a foretaste of what is in store in the artificial preparation of the oxytocic factor of the pituitary by Prof. de Vigneaud. And when we speak as chemists of nucleosides, proteins, or the oxytocic factor we are all the time thinking not so much of the specimen in the glass tube but of the way the atoms are joined together in each of the billions upon billions of molecules in the tiniest visible fragment of the material. May I be pardoned by the *cognoscenti*, I cannot forbear from repeating the results of a calculation made by Dr. Shapley, the eminent American astronomer, which illustrates very clearly the huge number of the molecules in any small parcel of matter. In any volume of air four-fifths of the particles are molecules of nitrogen, each consisting of two atoms. If, for example, a deep breath is exhaled the nitrogen molecules in it are rapidly dispersed and after a certain period, probably not more than a few years, perhaps less, they will be equally distributed throughout the atmosphere. The mass of the atmosphere is known approximately and when even distribution has been achieved each unit volume of air at the surface of the earth will contain between two and three of the nitrogen molecules that were present in the original volume distributed. Now to make it more dramatic we select some particular exhalation, preferably a long time back so as to make sure of the necessary even diffusion. Thus we could say that when Shakespeare was writing the first line of the second act of *Hamlet* he exhaled a breath and if you care to inhale a breath now—I sincerely hope you can all do that—it will contain two of the actual molecules exhaled by Shakespeare at that particular time. You would be very unlucky if you only got one and, if you were to capture three, you would belong to a fortunate minority.

The calculation leads to other interesting results. If you exhale a breath now, then, after the lapse of the necessary time, every breath inhaled by every living person on all occasions will contain two of the nitrogen molecules in that breath of yours.

It must be obvious that many of the molecules will be used more than once and the calculation takes no account of the small losses from the atmosphere due to escape, or the activities of Sir Alexander Fleck, among other nitrifying organisms.

The question which is often asked, and ought to be asked, is—how can you possibly know anything about the architecture of such exceedingly minute particles? The answer cannot be given in a few sentences but an analogy may help you to appreciate the possibility—again with apologies to those *cognoscenti*. A pure chemical substance is a collection of identical molecules. Let us compare a perceptible amount of it to a crate of identical clocks, each clock then represents a molecule. We reduce the clocks to a heap of metal filings, take a certain weight of these and apply a strong magnet. This takes out the iron, which we weigh and thus we get the percentage of iron in the whole of the clocks, which is also the percentage of iron in one clock. But it may be objected, you have started with the hypothesis that the molecules in a parcel of a pure substance are identical. How can you be sure of that? A short answer cannot be given; it depends on the recognition that certain properties, for example, many optical properties, are due to the summed effects of individual molecules, and on the elaboration of techniques for segregating molecules of the same kind. For example by crystallisation, distillation, diffusion, or by adsorption on surfaces.

The Whole Truth . . .

Justification of scientific theory has been obtained by the success of predictions and by the unanticipated convergence of more than one line of approach.

This is a commonplace of every part of science and the examples to be mentioned could be almost indefinitely extended. In all the cases the degree of coincidence becomes so great as to carry conviction that we have been vouchsafed, if not the whole truth, at least something very closely related to it.

Even the routine predictions of astronomers are a perpetual source of wonder but the circumstances of the discovery of Neptune were sensational. In 1843–4 J. C. Adams of Cambridge found that the perturbations of the orbit of Uranus could be fully explained by the existence of an outer planet and he accurately identified the position in which it should be found.

Quite independently, Le Verrier, of Paris, came to exactly the same conclusions and was more fortunate than Adams in securing the quick co-operation of practical astronomers, with the result that Neptune was discovered in the predicted place in the Heavens. It proved to be of the size expected and later was found to follow the expected orbit.

Again, near the beginning of the second decade of the century, Albert Einstein stated that his relativity theory required that the rays of light should be bent under the influence of a gravitational field. He was able to calculate the magnitude of the expected effect. Confirmation came from observations made on the occasions of the two next following total eclipses of the sun. This success was naturally particularly welcome in view of the novelty of the theoretical background and it doubtless accelerated the development of the new physics based on the work of Planck, Einstein and other pioneers.

The death of Einstein has evoked universal tributes of homage to the man and the philosopher. He was undoubtedly one of the greatest of men of science.

A third example of prediction is the successful release of nuclear energy, especially in the so-called hydrogen bomb. We must not allow the horror of the possible misuse of the weapon to blind us to the spectacular triumph of the achievement. It showed very plainly that nuclear physicists had been thinking on the right theoretical lines. Let us hope that they will continue to do so, 100% and not 99·9%. These matters are shrouded in secrecy but Press reports have suggested that just as the hydrogen bomb is initiated by a Mark-I atomic explosion, so the hydrogen bomb in its turn can initiate a vastly greater uranium explosion. In biological processes energy is taken up in steps by suitable relays to high levels, and an ordinary scientist cannot help wondering whether every possibility of setting fire to the lighter elements has quite certainly been excluded, if nuclear relay is taken to further stages.

Need to Relax Secrecy on Nuclear Energy

Do we really know enough about nuclear reactions to be sure that there is no loophole? Has every conceivable case been considered?

The physicists appear to be cocksure that this is so; they claim the 100%. But just as it is necessary that "justice shall be seen to have been done" I submit that it is desirable that the inner circle of advisers to Governments should not only be right but be "seen to be right". This can only be secured by a relaxation of secrecy on the scientific aspects of nuclear energy developments and by some form of international consultation before novel and greatly increased releases of energy are attempted.

The second class of welcome confirmations was the illumination of a topic from two or more distinct sources.

This is now a commonplace of many sciences, for example, again, of organic chemistry. Analytical researches lead to the determination of a molecular structure which may be confirmed, possibly after the lapse of years and in a different laboratory, by synthesis of the substance the molecules of which should possess that structure. If the synthetic product proves to be identical with that isolated from natural sources, the whole system of reasoning both on the analytical and synthetic sides receives important support. Even more

striking has been the validation of the conclusions of chemists by x-ray crystallography. At first this led to the confirmation of established structures, often with some additional information about the arrangement of the atoms in space. Later the x-ray studies were accessory to the first analytic studies. Thus in the case of penicillin, Mrs. Hodgkin and her collaborators were able to fasten upon one of the two alternative structures which the purely chemical researches indicated. Now the chemical and physical methods go hand-in-hand, with the crystal analysis tending to play a more important role than in the past, and destined to do so more and more in the future.

The Invisible becomes Perceptible

Another example may be mentioned. The chemical formula for a metal phthalocyanine had the shape of a four-leaved clover and the metal atom was placed at the centre. Robertson's electron-distribution diagram from x-ray evidence had the same discoid shape and the metal atom was where expected. Only a few years ago a special electron microscope cast the clover-leaf shadow of a single molecule of copper phthalocyanine on a fluorescent screen.

The necessary apparatus is not particularly complicated and can be purchased.

This was by no means the first time that a single molecule had become apparent to our senses. Owing to the great energy of certain particles carrying an electrical charge, and the invention of devices for amplifying very small currents, we have long been familiar with a variety of methods for observation of the effects of single particles. Crookes's spinthariscope, the Geiger counter, the Wilson cloud chamber and, bringing coals to Newcastle, the techniques developed in such an admirable manner by Prof. Powell and his school here in Bristol, for the study of single events at the atomic level; the study of the impact of cosmic rays on the sensitive emulsions of the photographic plate.

In other subjects there are very many examples of the confluence of streams springing from two sources. Examples are the dating of ancient objects by means of radioactive isotopes and the light shed on the movements of races by the hybridisation of plants.

The latter reference is to a hybrid cotton plant found in Peru. There the Porto Rican cotton plant married the Indian and the circumstances are consistent with the view that Indian voyagers reached South America in very early days.

All branches of knowledge are included in the definition of science; always provided that the record has been made without appeal to authority.

There is no philosophical line of demarcation that separates one branch of learning from another though the demeanour of many so-called humanists suggests that they perceive one.

A historian, formerly a colleague of mine, once declared that the absorbing interest of his subject was due to the badness of the evidence, but I think that was only another way of saying that he liked to get his teeth into a difficult problem.

Anti-scientific Propaganda

It is not necessary or desirable to pursue this unprofitable discussion ; our brother scientists on the Arts side will doubtless work out their own salvation. But it is opportune to add another voice of protest against the often repeated assertion, that "culture" is the preserve of students of some particular branches of knowledge, and is denied to others. What is meant by "culture"? If it is the ability to think clearly and to express thoughts in language, what evidence is there that physical and biological scientists lack these qualities?

The acerbity that characterises much of the anti-scientific propaganda strongly suggests that its basis is defensive rather than offensive.

In the meantime these persistent attacks do a great deal of harm by suggesting to young people that they will become automatons if they devote themselves to physical science and that in such a life they will not experience the warmth of human feeling.

What a travesty of the facts this is! The scientific discipline is indeed a hard one but it is most rewarding and full of living drama. Perhaps I may just have time to show one picture from the past. It concerns a beginner in research, but that young man was Louis Pasteur. It will be best to quote his own words from "Lectures on the Molecular Asymmetry of Natural Organic Products" (1860), reprinted by the Alembic Club of Edinburgh:

"When I began to devote myself to special work, I sought to strengthen myself in the knowledge of crystals, foreseeing the help that I should draw from this in my chemical researches. It seemed to me to be the simplest course, to take, as a guide, some rather extensive work on crystalline forms; to repeat all the measurements, and to compare my determinations with those of the author. In 1841, M. de la Provostaye, whose accuracy is well known, had published a beautiful piece of work on the crystalline forms of tartaric and paratartaric acids and of their salts. I made a study of this memoir. I crystallised tartaric acid and its salts, and investigated the forms of the crystals. But, as the work proceeded, I noticed that a very interesting fact had escaped the learned physicist. All the tartrates which I examined gave undoubted evidence of hemihedral faces.

"Now if we compare the disposition of the hemihedral faces on all the prisms of the primitive forms of the tartrates, when they are orientated in the same manner, this disposition is found to be the same.

"Herschel had already connected the hemihedry of quartz with the right or left rotatory power of the crystals and Pasteur saw that the hemihedry of the tartrates could be an outward and visible sign of the asymmetry of the molecules. Hence he was extremely interested in a note of Mitscherlich of 1844 stating that sodium ammonium tartrate and sodium ammonium paratartrate had identical crystal form and yet only the former was optically active in solution. He thought Mitscherlich must have failed to notice that the paratartrate was not hemihedral.

"I hastened therefore to re-investigate the crystalline form of Mitscherlich's two salts. I found, as a matter of fact, that the tartrate was hemihedral, like all the other tartrates which I had previously studied, but, strange to say, the paratartrate was hemihedral also. Only, the hemihedral faces which in the tartrate were all turned the same way, were, in the paratartrate inclined sometimes to the right and sometimes to the left. In spite of the unexpected character of this result, I continued to follow up my idea. I carefully separated the crystals which were hemihedral to the right from those hemihedral to the left, and examined their solutions separately in the polarising apparatus. I then saw with no less surprise than pleasure that the crystals hemihedral to the right deviated the plane of polarisation to the right, and that those hemihedral to the left deviated it to the left; and when I took an equal weight of each of the two kinds of crystals, the mixed solution was indifferent towards the light in consequence of the neutralisation of the two equal and opposite individual derivations.

A Dramatic Incident

"The announcement of the above facts naturally placed me in communication with Biot, who was not without doubts regarding their accuracy. Being charged with giving an account of them to the Academy, he made me come to him and repeat before his eyes the decisive experiment. He handed over to me some paratartaric acid which he had himself previously studied with particular care, and which he had found to be perfectly indifferent to polarised light. I prepared the double salt in his presence, with soda and ammonia which he had likewise desired to provide. The liquid was set aside for slow evaporation in one of his rooms. When it had furnished about 39 to 40 grams of crystals, he asked me to call at the Collége de France in order to collect them and isolate before him, by recognition of their crystallographic character, the right and the left crystals, requesting me to state once more whether I really affirmed that the

crystals which I should place at his right would deviate to the right, and the others to the left. This done, he told me that he would undertake the rest. He prepared the solutions with carefully measured quantities, and when ready to examine them in the polarising apparatus, he once more invited me to come into his room. He first placed in the apparatus the more interesting solution, that which ought to deviate to the left. Without even making a measurement, he saw by the appearance of the tints of the two images, ordinary and extraordinary, in the analyser, that there was a strong deviation to the left. Then, very visibly affected, the illustrious old man took me by the arm and said:

"'My dear child, I have loved science so much throughout my life that this makes my heart throb.'

"You will pardon me, gentlemen, these personal recollections which have never been effaced from my mind. In our day, and with our habits, they would offend in a scientific memoir, but they have seemed to me not out of place in an oral account; and perhaps the biological interest of such recollections will constittate one of the advantages of the kind of instruction which the Société Chimique inaugurates today.

"Indeed there is more here than personal reminiscences. In Biot's case the emotion of the scientific man was mingled with the personal pleasure of seeing his conjectures realised. For more than thirty years Biot had striven in vain to induce chemists to share his conviction that the study of rotatory polarisation offered one of the surest means of gaining a knowledge of the molecular constitution of substances."

Thus was the science of stereochemistry born. The main point of Pasteur's work was that he recognised that the optical rotatory power of the tartrates in *solution* showed that the molecules themselves must be asymmetric. The hemihedry of quartz was recognised as due to the asymmetric arrangement of symmetrical molecules in the crystal, like a male, or a female, screw. But the hemihedry of the tartrates, though due in the crystal to the same cause, persisted in the free molecules which were therefore characterised by asymmetry in a certain sense, all right-handed or all left-handed; all male screws or all female screws. A mechanical analogy is very useful here. If a pipe is almost filled with one screw and water is forced along it, the issuing stream will rotate, clockwise or anti-clockwise, according to the nature of the screw. The same thing happens if we pack the tube with small male screws, or small female screws, arranged at random. With an equal number of both kinds there would be no rotation of the issuing water. The single large screw corresponds to the quartz crystal, and the higgledy-piggledy small screws correspond to the freely moving asymmetric molecules of the tartrate in solution.

The philosophy of asymmetry is very intriguing. Only an asymmetric, I should perhaps say dissymmetric, agent can distinguish the right-hand from the left-hand varieties, and of course it was Pasteur himself who sorted out the hemihedral crystals oriented in the two mirror-image forms.

Recently, by a most ingenious application of crystal analysis, Bijvoet has been able to determine the configuration of naturally occurring tartaric acid, which is related to that of many other substances in what we call the L-glucose family. The convention used by stereochemists turned out to be correct, which is quite convenient. The chances for this outcome were naturally no better than even.

Admittedly this example of "atmosphere" relates to a very exceptional occasion and Pasteur was a very remarkable man, one of the greatest scientists of all time.

But all of us who have been privileged to take part in scientific life and research have had similar exciting, and may I add, emotional, experiences in our smaller ways.

Asymmetry: A Challenge to the Synthetic Chemist

The explanation of molecular asymmetry in terms of structure was given in 1875 by Le Bel and independently by van't Hoff. The latter was said by Kolbe "to have no taste for exact science. Mounted on his Pegasus, evidently borrowed from the veterinary stables (van't Hoff taught chemistry at the College of Veterinary Science at Utrecht) he thinks he can see the arrangement of the atoms in space". Nowadays the organic chemist has not completed a synthetic task until the various parts of the molecule have the desired type of asymmetry. Often a succession of screws has to be laid down in the correct order. Thus there are eight places in the cholesterol molecule which can be the source of asymmetric arrangement and that implies 256 possibilities of difference due only to the right- or left-handedness of the parts. And yet the one particular configuration of the cholesterol molecule has been constructed in the laboratory.

The task was equivalent to finding the right road at each of eight successive bifurcations.

Before straying too far from actual science I would like to say something about the use of speculation, which should always arise from some correlation which was hitherto unknown or unnoticed, or the significance of which has been underestimated, or thought to have been underestimated.

In the early stages it may be discouraging to study the literature; one can always find reasons there for believing that a new idea is not worth pursuing, or for that matter for saving oneself the trouble of doing an experiment. Later, having worked up an internal, self-generated pressure of enthusiasm, it is obligatory to face the hard facts already on record. Then, instead of weakly accepting a rebuff we shall at least put up some fight with "but on the other hand it might be that——"

At this point it may be realised that something really has been overlooked by one's predecessors and new crucial experiments must be devised to resolve one dubiety after another. Herein lies the safeguard, the final court of appeal is Nature herself.

The scope of the Association's interest is not clearly defined in our original "Objects" which I will read, because the early practice of printing them each year has long been abandoned.

"The Association contemplates no interference with the ground occupied by other institutions. Its objects are: To give a stronger impulse and a more systematic direction to scientific inquiry —to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another and with foreign philosophers—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress."

Our Sections now include the chief physical and biological sciences, Economics, Anthropology, and Archaeology, Psychology and Education, as well as Engineering, Forestry and Agriculture. There is also an active Division for the Social and International Relations of Science. All this evinces a real catholicity of interest; omissions are based on practical, rather than on theoretical considerations. For example, clinical medicine and surgery are well served by a number of other organisations.

The Universality of Science

An important aspect of science is its universality, and its fully international character only rendered possible by the axiomatic freedom it enjoys from authority and dogma. True there have been regrettable incidents such as that of the Misurinian genetics, but the body scientific has acquired considerable immunity against such fevers, which are now all but forgotten.

There is no such thing as British, or German, or Russian, or Jewish science, though it is true that the genius of many peoples has enabled them to make characteristic contributions. The French have a special lucidity of mind and expression, as well as elegance of technique, the Americans excel in organisation of research, the Germans in thoroughness, the Japanese in attention to detail, whilst the Jews have imagination and theoretical insight. There is much overlapping of course; we may find a Memmling among the Florentines.

It has occurred to me to wonder wherein lies our own particular merit.

The pioneering spirit of our illustrious forefathers is everywhere acclaimed and there is even now little sign of any decline in our initiative. Can it be at least partly the result of not working so hard that no time is left for reflection? We certainly defend our leisure from encroachments with special tenacity. Again it may be that we are in a certain sense undisciplined; but I will not elaborate that suggestion. Science as a common international possession and the world-wide co-operation in its development must be bulwarks of peace. Here we have a realisable asset of the greatest possible positive value. The brotherhood of scientists is a reality. It is fortunately not unique; there is a similar fraternity among sportsmen, musicians, chess-players and other categories of enthusiasts, not encumbered by the so-called ideologies.

It should be clear from the definition that religion in so far as it is authoritarian and dogmatic, can make no contribution to science. But it is no paradox to say there is room for both science and religion within the mind of a man.

Indeed we have ample proof that this is so from everyday experience. Many of the greatest of scientists have been deeply religious men and eminent divines have been excellent scientists.

Testimony to the help afforded to the Royal Society and to our own Association by churchmen may be found in the records and is still apparent on inspection.

At the Bristol Meeting of 1836 the Presidents of Sections (A), (B), (C) and (D) were all clergymen.

On the other hand many scientists have been, and are, free-thinkers. Yet, the two groups should be united in the unflinching pursuit of the truth and in a spirit of tolerance.

Titles such as "Science and Religion" tend to confuse the simple issue which relates to "Scientists" and not to "Science". Again the uncertainties of modern physics are now considered by some to justify mystical analogies.

It would appear that there are many who feel an irresistible urge to fill up all gaps in knowledge by their own inventions. Such intuitive speculation can indicate useful working hypotheses but it is not science *per se*.

Actually physics is a much more complete and satisfactory system now than it was in the later nineteenth century. It is true that we are perplexed by many new problems, but at least we are aware that they exist. That is an improvement on complacency founded on ignorance. The human mind can be shown to be inadequate in several ways. Speaking subject to correction by philosophers it would seem that certain alternatives that are logically mutually exclusive are equally inconceivable by us. The conceptions of a continuum or a discontinuum, of creation or indefinite projection of reality into the past cannot be grasped by the human mind. Yet the fact that we find something to be incredible is no proof that it does not exist. Hence physicists are content to derive expressions for the description of phenomena with the minimum of extraneous hypothesis.

Fifty years ago an ether was an article of faith; there could be no action at a distance without an intervening link, electro-magnetic waves must occur in something, and so on. But each invented ether was about as incredible as the absence of one. Nearly fifty years ago I remember being fascinated by Osborne Reynolds's "Inversion of Ideas as to the Structure of the Universe". This postulated a very dense ether consisting of minute grains. Matter was a negative inequality in this ether, that is, an absence of grains, a kind of hole. It could be shown that the inverse square law would govern the attraction of such holes. Mathematical physicists have evidently found it hard or impossible to use this theory, but I well remember thinking more or less as follows: Yes, but what are the grains made of? They have been invested with some of the properties of matter and they are a kind of engineer's dream of perfect Daltonian atoms on a very small scale. The argument is quite inconclusive, but I found then, and have always found since, that the idea of a continuum, even inside a grain of the ether was, and is, repugnant. So nowadays we just arrange to do without this comfortable resource of an ether, though I have been told that Prof. Dirac may revive the idea in some form or another—which few of us will understand.

The Scientist as a Citizen

Another feature of the complex make-up of the scientist is that he is a citizen and owes a duty to the State.

This leads to obvious conclusions in most respects but where do we stand in regard to the invention of military weapons?

In wartime few of us entertained any doubts about this; it was our clear duty to help our country to the best of our ability. Now it is a matter for the conscience of the individual, taking into consideration that we have not yet achieved a real peace.

The position is one of unstable equilibrium and it still seems that as citizens we should do all in our power to strengthen the hands of our leaders, in whom we have placed our trust, and who we believe are sincere in their desire to achieve universal peace among the nations. Even the terrible nuclear-energy weapons must be developed by our scientists in peacetime so as to build up the necessary potential of deterrence, our only defence against extinction.

I have mentioned only two or three of the personal problems of scientists but there are, as is very well known, many national questions affecting scientists and on these I can say very little in this Address. The chief is perhaps the training of scientists which starts in the Schools and involves the supply of science teachers. This matter has been raised in the General Committee here in Bristol. We hope to make some small contribution to a solution of difficulties that are the cause of considerable justified anxiety among industrialists.

Finally, I want to say a word about technology and technologists. Dr. Holmyard and Prof. Singer have, in the first volume of their monumental work on the History of Technology, pointed out that it all started with handicraft. The modern technologist is still a man with know-how and can-do, whether he be technician, craftsman, designer or supervisor, and he is equipped with knowledge of general and special scientific and engineering subjects.

Britain's Lack of Technologists

It is generally agreed that we have far too few technologists in this country and that our economic survival is improbable unless we take some drastic steps to remedy the situation. The proposals that have been made are admirable as far as they go, but, in the opinion of many who are well qualified to judge, they do not go nearly far enough.

It is doubtful whether any scheme tied to existing Institutions can meet the requirements and to come right down to ground level, I suggest that we need a "Technology Grants Committee", independent of any other body and with power to expend a very considerable sum of money.

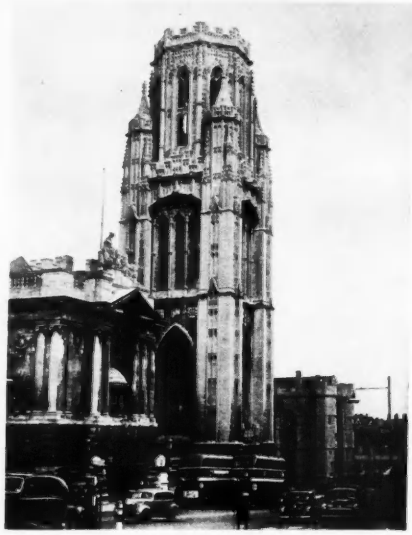
This idea has probably already been adumbrated. In which case I think it should be supported.

I must tender humble apologies for the attempt to cover so many topics, and so inadequately. At least I have avoided for you the dullness of which King Gama complained. There *will* be plenty of things to grumble at.

SCIENCE AND TECHNOLOGY IN BRISTOL

PROF. W. E. GARNER, D.Sc., F.R.S., C.B.E.

Leverhulme Professor of Physical Chemistry, University of Bristol, 1927–54



The University Tower

The development of Bristol as a trading, and later as an industrial, centre owed much to its being a sheltered tidal harbour and a bridge town on the Avon. It was not in existence in Roman times although there was a Roman ferry at Sea Mills, three miles distant, and there were many Roman villas in the vicinity. It was beginning to achieve some significance in Saxon times, but until the Norman Conquest it grew in size very slowly. Its first activities as a port were concerned with trade with the Norsemen in Ireland, and by the 12th century there was considerable trade with southern France, northern Spain and Portugal. Thereafter the range of its trade continuously expanded to include the Mediterranean, Iceland, the West Indies, America and Africa, and during some centuries its great foreign trade made Bristol second only to London. The development of technology went hand in hand with the growth of its commerce.

METALLURGY

In the words of Agricola, "Britain produces gold, silver and other metals—the booty of victory." Lead was extracted in the Mendips in pre-Roman times, and was extensively smelted at Charterhouse on the top of the Mendips by the Romans. Early lead smelting was conducted near the mines, in an exposed place where the open-hearth furnaces were operated in the draught from the wind. The earliest pigs found in the district were made in A.D. 49 and from these the silver had been extracted. Iron was also made by the Romans at Chew Park Farm, and this metal was one of Bristol's exports to Ireland in the 12th century.

Bristol was a natural centre for a metallurgical industry based on the Mendip and Cornish mines, since it had its own coal-field and ample water supplies in the vicinity. In spite of these advantages, it does not appear to have played much part in extractive metallurgy until the end of the 16th century, and then not very successfully. This arose from attempts to make brass at Bristol Castle from calamine ore (zinc carbonate). Brass was made by the Romans by heating calamine, copper and charcoal together, and by the same method on the Continent in the 16th century. In Bristol the copper was obtained by smelting Cornish ores, the calamine came from the Mendips, and the charcoal probably from Kingswood Forest. With improvements in smelting methods the copper and brass industry was gradually consolidated in Bristol and by the 18th century the Bristol Brass Company was reputed to be "the most considerable brass house in Europe". The first reverberatory furnace used in copper smelting was reputed to have been built in Bristol possibly under German tutelege, and the first zinc metal produced on a large scale in Europe was made at Warmley, near Bristol, under a patent of 1758 by William Champion. It was isolated by the alchemical method, distillation *per descensum*. On heating zinc metal with copper a superior kind of brass was manufactured in Bristol.

From sulphide ores, a valuable by-product, sulphuric acid is derived. One of Bristol's chief contributions to the development of the sulphuric acid industry was the patent by Peregrine Phillips in 1831, which describes what is virtually the contact process of today.

One of the earliest of Bristol's chemical industries was the manufacture of "grey sope". It is recorded by Richard of Devizes that soap was made in Bristol as early as 1180, and in 1242 it was sold in London at a penny a pound. At first it was made from olive oil imported from France which was converted into soap by treatment with alkali from wood ashes, although later animal fat was used. This gave a soft soap which was hardened with brine. Bristol had a virtual monopoly of soap manufacture in Britain for about 400 years, but in 1631 London citizens were given privileges by Charles I

and Bristol soap makers were taxed and fined nearly out of existence. After 1745 the industry re-established itself and it has continued to this day. The introduction of the Leblanc process into this country by Muspratt in 1804 for the manufacture of sodium carbonate was stimulated by the requirements for alkali of the soap industry. The Leblanc process was operated in Bristol for many years.

CERAMICS AND GLASS

A prominent feature of the sky-line in Bristol in the 18th and 19th centuries was the conical structures with their plumes of smoke used for the manufacture of glass. The first recorded glass house in Bristol was built by a Venetian in 1651, but there were fifteen glass houses by 1750. Flint and crown glass was made, but most of the glass was for bottles and window glass. Decorated and cut table glass, enamelled and coloured glass were also manufactured in Bristol and Nailsea and are much valued by collectors.

The Romans made pottery in the district, and rough pottery was made by peasant potters throughout medieval times. In the late Stuart period, the drinking of tea and coffee led to the introduction of porcelain from China, and to the imitation of Chinese porcelain by the glazing of pottery with tin enamels. The process was discovered at Delft in Holland, but in 1650 a pottery was in operation at Brislington making the so-called "Bristol Delft". In various factories it continued to be manufactured in Bristol up to the 19th century.

Delft and pewter were, however, being replaced by true porcelain during the 18th century and the composition of the porcelain underwent many changes before it was standardised in its present form as bone china. William Cooksworthy, about 1748, engaged in a research into the composition of china, and introduced the use of china clay from Cornwall for porcelain manufacture, and thereby laying the foundation of the china clay industry of Cornwall. Several of Cooksworthy's compositions were manufactured in Bristol and gave products of high artistic quality. A soft paste china, made in Lowdin's glass house, ultimately was taken over by the Worcester China Company. A hard paste china, with a higher silica content and a higher firing temperature, was made in Champion's factory, and this was ultimately moved to Staffordshire. The ceramic industry is, however, still represented in Bristol.

SUGAR

Bristol imported sugar from the plantations of Spain and Portugal in the 14th century and, with the discovery of America and the opening of the West Indian trade, became an important refining centre, partly because of its facilities as a port and partly because of its plentiful supplies of cheap coal and water. Sugar refining was one of Bristol's chief sources of wealth between 1600 and 1800, after which there was a sharp decline due to the emergence of Liverpool as a port and the development of the industrial north. Bristol has however continued to be interested in the food industries (one specific example is that of cocoa with which the firm of Fry's has been connected ever since 1728), and many food factories are grouped around the Avonmouth docks. The manufacture of starch in Bristol commenced in 1818.

ENGINEERING

The engineering adventures of Bristol have been mostly associated with its docks, roads, railways and bridges. The well-known Clifton Suspension Bridge was built to the revolutionary designs of I. K. Brunel, but there were in addition two local engineers, Motley and Dredge, who were his competitors. They contributed much to modern design by way of new ideas which they incorporated in the bridges they built in the neighbourhood. The *Great Western*, the first steamer to cross the Atlantic in 1837, and the *Great Britain*, the first iron ocean-going ship in the world, were designed by Brunel and built in Bristol. The former was in course of construction during the first visit of the British Association to Bristol in 1836. Brunel played an important role in placing Britain in the forefront of bridge and steamer construction. He was also the chief engineer of the Great Western Railway, and, in order to produce creosote for the preservation of its sleepers, set up a small factory for the distillation of coal tar. This initiated the tar distillation industry in Bristol which is now a large business.

ALCHEMY

In the medieval port of Bristol Thomas Norton wrote "The Ordinal of Alchemy", which was printed in English in 1652 in Ashmole's *Theatrum Chemicum Britannicum*. In words appropriate to the transmutation of metals both ancient and modern, he wrote:

> For this science must ever secret be
> The cause whereof is this as you shall see:
> If one evil man had have of all his will
> All Christian Peace he might hastilie spill
> and with his pride he might pull downe
> Rightful Kings and Princes of renowne.

The richness of the flora in the environs of Bristol attracted many famous botanists of the 16th and 17th centuries, and the rare plants they found have been described in the Herbals of 1550 onwards. Among these were such famous botanists as William Turner, John Gerard, John Parkinson, Thomas Johnson, Christopher Merritt and Sir Joseph Banks. The famous geologist, John Woodward (1665–1728), devoted considerable attention to the geology and fossils of Somersetshire and Gloucestershire, including the coal measures of the Mendip area. John Strachey (1671–1743), a local geologist, also studied the fossils of the coal measures and was the first to point out that fossils could be used to identify coal seams. William Smith, while superintending the construction of the Somerset coal canal, noted the regularity with which "Nature had disposed of these singular production [fossils] and assigned each class its stratum". Thus the foundations of modern stratigraphy were laid in the Bristol area.

In Thomas Beddoes Pneumatic Medical Institution at

Hotwells, Humphry Davy in 1799 discovered that pure nitrous oxide could be inhaled with safety and that it produced intoxication. This "laughing gas" he suggested might be used in surgical operations since when inhaled it appeared capable of destroying pain. Davy also commenced in this institution his researches on electrolysis, which he continued on his appointment in 1801 as lecturer at the Royal Institution, London.

EDUCATION IN SCIENCE

The development of science in Bristol's scholastic institutions came rather later than in some other industrial centres. Bristol was influenced by the educational revival in the early part of the 19th century and developments occurred along three main channels: (1) an education based on literature and science of university standard, (2) technical education, (3) medical education. It took nearly a century for these three streams to merge and lead to the creation of a university in Bristol.

Let us consider these three lines of development a little more closely. With regard to the first, we find that the need for higher education from the Middle Ages up to the middle of the 18th century was met by sending gifted boys to Oxford and Cambridge. In 1831, attempts were made to establish Bristol College in Park Row to give a classical and mathematical education, but this failed and its successor, the Bishop's College, was equally short-lived. On August 9, 1876, the Board of Trade licensed the incorporation of University College, Bristol, for the teaching of literature and science. The prime movers were Prebendary Percival, Jowett, the Master of Balliol College, Oxford, who supported it financially through difficult years, Lewis Fry, who was a generous supporter of the college, and the Bristol Medical School.

Technical instruction in medieval times was given to apprentices under the regulation of the guilds, while the teaching of the three R's to children of artisans was provided in some of the ancient schools of Bristol.

The premises which University College occupied temporarily on its foundation in 1876.

However, little thought was given to systematic technical education until the early part of the 19th century. The Merchant Venturers of Bristol were incorporated in 1552 and played a great part in English exploration, overseas trade and colonisation. They were also very active in promoting technical education. In the 18th century they established a navigational school to teach technical matters to those going to sea, and when in the 19th century the idea was mooted of trade schools to teach the principles of manufacturing and technical pursuits, they played a dominant role. In 1856 the Bristol Diocesan School was founded to carry out these ideas; in 1882 the school was amalgamated with the Navigational School and transferred to buildings in Unity Street by the Merchant Venturers. In 1894, it became the Merchant Venturers Technical College.

Lastly we come to medical education. The Bristol Medical School began in 1833 in a building in Old Park which still stands. The history of the medical school as described by Dr. G. Parker makes very interesting reading. In 1873 it decided to link up with those who were anxious to found a college of literature and science in the west of England, and the school gave £1000 towards the foundation of University College. It became affiliated with the College in 1879, but was not fully incorporated as its Medical Faculty until 1893.

BRISTOL'S UNIVERSITY

Bristol's University College made a modest beginning in a Georgian house in Park Row, rented at £50 per annum. This building was occupied and used for science teaching for seven years. The college was fortunate in attracting a young academic staff within the first few years, many of whom were to become distinguished later, as for example William Ramsay, J. N. Collie, D. Orme Masson, Silvanus P. Thompson, W. J. Sollas and H. S. Hele-shaw. The college ran both day and evening classes, and in addition some members of the staff gave extramural lectures to the general public and to juveniles. With the financial support of London's Worshipful Company of Clothworkers Ramsay gave courses of lectures to the operatives of the woollen industries of the south-west at Trowbridge and Frome, though he expressed doubts about the value of these particular courses since the audiences "knew nothing of science, but had the whole practice of their art". Silvanus P. Thompson, who was a very gifted public lecturer, afterwards became a lecturer for the Gilchrist Trust.

After a few years the accommodation proved to be inadequate for the number of students enrolled, and the Council of University College bought an acre of land adjacent to Tyndalls Park as a site for buildings. In 1880 the Medical School occupied the first building to be completed, and three years later accommodation was provided for science and engineering. In the middle of this building programme, William Ramsay, who was then only twenty-nine years old, was made Principal. He stayed on until 1887. Ramsay was followed by Lloyd Morgan, who, with his long beard, was a prominent figure in Bristol and Clifton. He was a

THE UNIVERSITY'S NEW ENGINEERING LABORATORY

well-known philosopher and scientist, who had made important contributions to the study of animal behaviour. He was in charge of several of the science departments for some years. He inspired confidence in Bristol citizens that the College was a centre of real learning and interested in knowledge for its own sake.

THE UNIVERSITY RECEIVES ITS CHARTER

By 1909 public opinion had been prepared for the next step in the provision of higher education in Bristol. University College had established itself under Lloyd Morgan as a worth-while institution, and the University Colston Research Society, founded in 1898 to support scientific research in the college, had convinced the citizens of Bristol that more support was needed for science. Morris W. Travers took full advantage of the favourable situation, and the support of the Merchant Venturers was secured. The final act before the granting of the University charter in 1909 was a munificent gift by Henry Overton Wills of £100,000.

After the granting of the charter, agreement was reached with the Merchant Venturers whereby the Faculty of Engineering was housed in the Technical College. A new Chemistry and Physiology wing was built in 1909, and the University's administration and Arts Faculty moved to the new buildings erected in Queen's Road, so setting free a greatly increased space in the old buildings for the departments of Physics, Geology, Biological and Medical Sciences. The next stage in the expansion was a new Physics building on the Royal Fort grounds in 1927, the generous gift of Harry Wills, and this was followed by a new wing for Biology in 1939.

In 1903 the National Fruit and Cider Institute had been founded at Long Ashton, as an experimental station concerned with the scientific problems of the Cider Industry. Later it was converted into a Research Station under Government auspices, and the University was asked by the Board of Agriculture to be responsible for its administration, an arrangement which has worked out very happily ever since.

Another major development occurred after the Second World War, when the Ministry of Agriculture and Fisheries financed the establishment of teaching facilities in veterinary science in the University. Pre-clinical laboratories were erected near the University in Park Row, and the University built clinical laboratories in association with an experimental farm at Langford House in Somerset.

THE SCIENCE DEPARTMENTS

Most of the present science departments had their origin in University College, although some were only in embryonic form as inclusions in other departments.

The first two professors of Physics were also in charge of electrical engineering. Silvanus P. Thompson (1876–85) is mainly remembered as a very gifted public lecturer and as a pioneer in urging the needs of technical education. His successor, A. P. Chattock, was a very modest man, who had a great influence in the building up of the experimental school of physics. He had worked with Sir Oliver Lodge at Liverpool, who once said that if he had taken Chattock's advice he would have discovered Hertzian waves. At Bristol he initiated various lines of research on the ionisation of gases in the electric discharge and on magnetism, and this fruitful work has been continued by his students in Bristol and other Universities. Chattock had an important influence on aeroplane design, through his invention of the pressure gauge which Stanton proceeded

Prof. Lloyd Morgan (1852–1936), who was Principal of University College, Bristol, from 1887 to 1910.

to use in the early wind tunnels of the National Physical Laboratory. A. M. Tyndall, who followed Chattock in 1927, persuaded Harry Wills to build the present Physics Department. He also succeeded in collecting funds from Melville Wills and the Rockefeller Foundation for the foundation of substantial fellowships for physical research. These proved most valuable during the Hitler purge of the thirties, and they made it possible for many able German physicists to stay for a time at the Royal Fort, adding variety to the experience of the department. The present excellent balance between theoretical and experimental physics is largely due to Tyndall, who appointed first Lennard-Jones and subsequently Mott to a Chair of Theoretical Physics. Although the recent contributions of the department have been made mainly in solid state physics and nuclear physics, there has been considerable flexibility at Bristol, permitting work to be done on the photographic plate, new microscopes, magnetism, the x-ray structure of long chain compounds, high-altitude balloons and other topics.

The Engineering Departments both in the days of University College and in the Merchant Venturers' Technical College have had a strong mathematical bias. This is exemplified by the work of H. S. Hele-shaw (1881–5), who made important contributions to kinematics, mechanical integration, continuous calculating machines and hydrodynamics. Inspired by the Tay Bridge disaster, he invented an integrating manometer for measuring both wind velocity and direction. In the Merchant Venturers' Technical College research was done on the strength of materials by A. Robertson, and on frame structures (including those of the R101 airship). The Engineering Faculty, which owes its present form largely to the organising abilities of A. Robertson, has recently moved into a new building on the Royal Fort site, and the main subjects it is investigating are the structures of aeroplanes, bridges and ships, aeroelasticity, strength of materials, fatigue and plasticity of metals and electrical light power engineering.

The Mathematics Departments are at present housed in the same building as Physics, but shortly they will become the near neighbours of the Engineering Faculty. In pure mathematics their current researches deal with algebra, theory of numbers, mathematical logic, topology and other topics, while some work on mathematical logic has been done in collaboration with the Philosophy Department. In applied mathematics investigations are being made into problems of fluid dynamics, such as arise in the high-speed flight of aircraft. Studies are also being made of supersonic and transonic flow, boundary layers and the diffraction of shock waves and sound waves.

There has been a succession of active schools of research in chemistry since the formation of the College. Ramsay and Sidney Young commenced their collaboration at Bristol in 1882. Ramsay learnt glassblowing from Young, and together they invented many devices now in common use for the handling of gases and the maintaining of constant temperatures. They established some of the classical thermodynamic relationships between the physical properties of liquids. When Ramsay went to London's University College, Young turned his attention to the fractionation of liquids, and his book on this subject is now regarded as a classic. James W. McBain did pioneer work on the structure of soaps which was of considerable interest to the industry, and this led to the foundation by Lord Leverhulme in 1919 of the Chair of Physical Chemistry. Morris W. Travers and Francis Francis were responsible for planning the present building of the Chemistry Department in Woodland Road in 1909, which is still, after forty-five years, convenient for teaching and research. Travers started the movement which led to the granting of the University charter. Francis was Pro-Vice-Chancellor for eleven years, during which time the details of University government were being evolved. Since the Second World War there has been a considerable expansion of the department into temporary buildings to meet the needs of research of organic and physical chemistry.

W. J. Sollas, who was head of the Geology and Zoology Department during the period 1876–83, combined his University duties with those of the curatorship of the Bristol Museum. His main interests were paleontological, but he carried out research on living sponges as well as their fossil ancestors. This led to his use of the spicules of marine sponges to trace tidal movements in the Severn estuary, a study of practical significance in showing the probable movements of Bristol sewage. The research activities of the University's geologists and biologists continued in some fields along lines similar to those followed by the gifted amateurs of the Bristol Naturalists Society. Thus S. H. Reynolds, who was Professor of Zoology and Geology, continued the work of R. Vaughan on the divisions in the Carboniferous as indicated by its fossils; later A. E. Truman did for the coal measures what Vaughan had done for the

Carboniferous Limestone. The present Geology Department is shortly to be transferred into the new block on the Royal Fort site. Its research consists of independent personal work on the study of the history of rocks, as shown by its fossils, ranging from the Jurassic to the Pre-Cambrian both in England and abroad. It has taken part in several expeditions to Greenland.

The botanical garden made by A. Leipner in 1882 on waste land adjoining the College buildings was expanded in 1913 across Woodland Road to give the Hiatt Baker Garden. Brebner (1901–5) studied the anatomy of ferns, and J. H. Priestley (1905–11) investigated photosynthesis and the effect of electrical discharges on crops. He was succeeded by A. Darbyshire (1911–34), who became a well-known authority on lichens. Valuable herbaria were presented by Father Leader, J. W. White and Miss E. Armitage, and these are all housed in an extension built in 1939. The present activities of the department are grouped about biochemical physiology, mycology and the ecology of plants.

The Zoology Department was developed by C. M. Yonge, whose main researches while at Bristol were on the biology of corals. He was also responsible for a detailed biological survey of the Bristol Channel. The department is at the present time engaged on a wide range of researches, both pure and applied; these include investigations on the effects of very high pressures on aquatic animals, early movements in embryos, daily rise and fall of plankton in the sea, insect physiology and evolution, and animal parasitology, and permeability studies with radioactive tracers.

A Chair of Anatomy was created in 1894. E. Fawcett, the first holder, was well known for his studies of the changes in the brain of human embryos, and his accurate and artistic drawings of microscopic sections. He was responsible for the revival of the Speleological Society in 1919 and supervised the valuable finds of man and mammals from Avelines Hole. Edgworth, as Professor of Pathology, carried out a zoological research into the development of the jaw muscles of embryos. The present medical staff is scattered about Bristol, some being in the hospitals, some in the University buildings and some in Canynge Hall. The main lines of medical research in the faculty are: the requirements of amino acids in the diet and their relation to diseases of the liver and kidney (especially in the tropics), development of cardiac surgery, research on cancer, statistical medical research, studies of the lymphatic system and bone marrow in relation to blood formation. Other research workers are concerned with bacteriological and veterinary problems.

Continuity in the development of research has been a feature in some departments. This is encouraged when the head of a department hands on the torch to his lecturer who succeeds him as professor, or appointments to chairs are made of individuals whose scientific interests lie in the same fields as those of their predecessors. Ramsay's studies of the properties of pure compounds in 1880 led to a line of development which survives to this day. This line passes through Young on

Polythene balloon used by Prof. C. F. Powell's team for cosmic ray research immediately before launch at Cardington. The record altitude reached with a load of about 50 kilograms was 107,000 feet. Volume when fully inflated 11,000 cubic metres.

hydrocarbons to Francis, Piper and Malkin on the structure of long chain compounds. There has also been continuity in the physics work at Bristol; for example we find that the work of Chattock and Tyndall on ionisation has had its influence on the application of the photographic plate to studies of cosmic rays. In the Department of Engineering much attention has been given over many years to structures and strength of materials, which links up with the earlier activities of Brunel in the district. In Geology there has been a local interest in the characterisation of rocks by fossils which dates back to Strachey in pre-University College days. This interest was strengthened by the close relations existing in the early days of the College and University between the departments of Geology and Zoology.

It is, however, a healthy symptom that universities import new blood from outside and replace some new lamps for old. Thus the fields of theoretical and solid physics were opened up by scientists from other universities. In organic chemistry researches on carbohydrates and macro-cyclic compounds were importations from the outside world. In the case of new ventures like aeronautics and veterinary science, it was unavoidable that outside experience should be sought. On the whole, a reasonable balance has been kept between the development of a Bristol tradition in research and the importation of new ideas.

THE FATIGUE OF METALS

PHILIP THORNTON, A.I.M.
Battersea College of Technology

Almost 100 years ago, the then existent Board of Trade commissioned an engineer—Sir William Fairbairn—to investigate a series of unusual breakages found to be occurring in railway waggon axles and various other metal parts. These failures had occurred quite suddenly, with little or no warning, and examination of them suggested that the metal had broken as if it were brittle.

This latter point was intriguing, because, in point of fact, many of the failures had occurred in those metals or alloys noted for their great ductility. In addition the broken faces were found to be very smooth and bright, and often showed characteristic shell-like markings. They were very different in appearance from those which were normally encountered.

To Fairbairn, and others who were aware of the trouble, the peculiarities of the fractures were overshadowed by the alarming but reliable information that, at no time during their service life, had the parts been stressed to a value even remotely approaching their theoretical breaking stress as indicated by laboratory tests. Normally in such tests, either the component was loaded until it broke—or the tensile strength of the material was measured by noting the force required to pull a bar of known cross-sectional area into two pieces.

Information so acquired, concerning the mechanical properties of metals, was naturally the prime factor in design calculations. If it were true, therefore, that metals could break in service when stressed to values but a fraction of their theoretical strength, then the future heralded some unpleasant, if not catastrophic, failures.

Two theories were prevalent at the time to explain the phenomena. The first suggested that metals aged, and that consequently their mechanical properties deteriorated with time. The other suggested that the strength of a metal varied with the manner in which the stress was applied.

In his classic researches Fairbairn disproved the first theory, by loading a metal bar to just below its breaking point and leaving it in this condition for four years. After this time had elapsed, the metal still had not failed, nor did it show any sign of doing so. Secondly, he subjected a wrought iron girder—theoretically capable of resisting 12 tons—to a maximum alternating load slightly in excess of 3 tons. After this load had been placed on and taken off the girder some 3 million times, the metal broke quite suddenly, with no prior warning. Examination of the fracture showed it to be similar to those occurring in service.

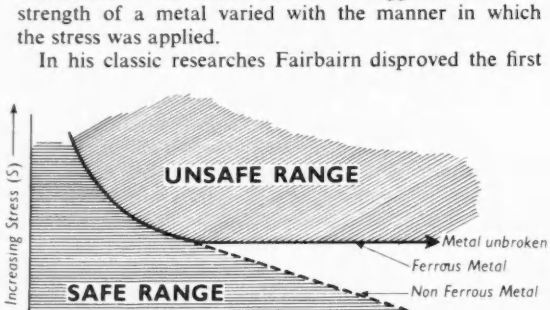


FIG. 1. Typical S N curves for a ferrous and non-ferrous metal. Such curves indicate the life of a component for any given stress, or the maximum stress permissible for any required life.

Thus, Fairbairn's work corroborated the second hypothesis and indicated that fluctuating loads could—after a certain time—cause fracture even though the applied load was but a fraction of the theoretical strength of the metal or alloy. Such failures became known as fatigue failures.

Further investigations followed and indicated that there was a relationship between the applied load (S) and the number of applications (N) of that load required to cause fracture. This ratio could be plotted, as in Fig. 1. The area above the curve indicates an unsafe combination of S and N—while that below the curve indicates a safe one.

Fig. 1 shows a typical S/N curve for steel and a non-ferrous alloy. It will be seen that the former exhibits a marked horizontal section. This implies that below a certain stress—commonly referred to as the fatigue limit—an infinite number of load applications still will not result in a fatigue fracture. No such marked fatigue limit is observed with many non-ferrous alloys.

This gives rise to the disturbing thought that, above a certain stress in ferrous alloys—or at any stress in some non-ferrous alloys—each load application does "something" to the metal, and that this "something" is slowly but surely cumulative, and finally results in fracture.

Perhaps as you read this, you may be travelling—by road, rail, or possibly by air. It is not a pleasant thought to imagine that some vital part has perhaps only a few stress applications in hand before sudden and complete fracture.

Neville Shute, you may remember, exploited this theme in his novel *No Highway*. The recent Comet disasters have given this story more than a dash of prophecy. Metal failure can be just a nuisance or can result in a catastrophe. The speed and complexity of modern travel puts the emphasis on the latter. As the majority of all metal breakages in service result from fatigue it will be appreciated why the subject has been so intensively studied recently and why it plays such an important part in modern design and planning.

The most reliable information on susceptibility to fatigue is obtained by subjecting a full-size component to all the conditions and stresses it will experience in service and observing, under laboratory conditions, its

life and behaviour. The difficulty is, however, to predict all the factors which affect service life. For example, the crankshafts in the engines of the Graf-Zeppelin ran satisfactorily in test beds—but rapidly broke when in the air, because of excessive and unexpected vibration.

Fatigue is, as yet, still basically unexplained. The whole subject abounds in intriguing facts and not the least of these is the cumulative action which results from repeated stress applications. When fatigue tests on the same metal or alloy are repeated many times, however carefully they are conducted, the results are never completely reproducible. The same general form and position of the S/N curve is, however, obtained. Every load application may be likened to putting marbles in a paper bag. After a certain number are put in, the bag bursts. The smaller the marbles the more of them required—the larger, the fewer. In this analogy the strength of the bag will be the intrinsic fatigue resistance of the metal or alloy.

What happens in the metal at each loading and how can this effect accumulate and result in fracture? No commonly accepted theory is available to date, but the following comments suggest a possible explanation.

When a metal is stressed it first deforms elastically, then, if it is ductile, above a certain stress value, known as the elastic limit, a sliding of one part of a metal crystal over the other occurs and plastic permanent deformation results. This sliding motion, which is in reality composed of the relative movement of adjacent atomic planes one over the other, results in an increase in the metal's resistance to further movement. Thus plastic deformation of metals increases their strength and hardness, and results in that attribute known as work-hardening.

THE EFFECT OF INCLUSIONS

Even the purest form of a metal contains some impurities, the commonest of which are non-metallic inclusions. These act to weaken the metal because, as they constitute a discontinuity in the metal structure, any generally applied load tends to be increased in the vicinity of the inclusion. Fig. 2 illustrates the "stress-raising" action of such an impurity. More important than the internal conditions, the shape and nature of the metal surface may result in high local stress concentration. For example, sharp corners, deep scratches and other surface blemishes are extremely harmful.

Therefore, at specific points in the metal, the actual stress may be much larger than that indicated by the applied load. With static loading, provided the applied load is large enough, the inclusions or surface factors will raise the local stress to a value in excess of the elastic limit, and plastic deformation and work-hardening will then result. These two effects will cause a more even distribution of the applied load and to some extent nullify the effect of the stress raiser. If the load is fluctuating—for example, if the metal is alternately stressed in tension and then compression—the effect of the stress raiser will be accentuated because there will be little lasting distribution of the stress. Instead plastic deformation of a reciprocating, or backward and forward, nature will occur as the high local alternating stress forces the atom plane to slide first one way, then another. As plastic deformation increases, so the amount of strengthening or work-hardening of the metal increases. A maximum value will finally be attained when the metal can deform no further, and is consequently fully work-hardened.

Consider such a reciprocating movement next to a stress raiser. Either this small amount of metal will work-harden to such an extent as to resist the high local stress (in which case, the applied load is below the fatigue limit), or the fully work-hardened metal will still not be strong enough to resist the local stress and a crack will form. This will be the condition when the applied load is above the fatigue limit.

Every stress application causes some slip and work-hardening, but it will not be until the metal is fully work-hardened that the absence of deformation prevents any distribution of the load and results in crack formation in the locally brittle material. Once a fatigue crack has formed, it can grow by a similar mechanism of stress concentration at the tip of the crack causing high local stress—slip—work-hardening, then further cracking. This form of crack growth gives rise to the observed shell-like markings on the broken faces, as illustrated in Fig. 3.

As the small local plastic deformation which results from an alternating load is in a backward and forward direction, although fracture occurs after the same total

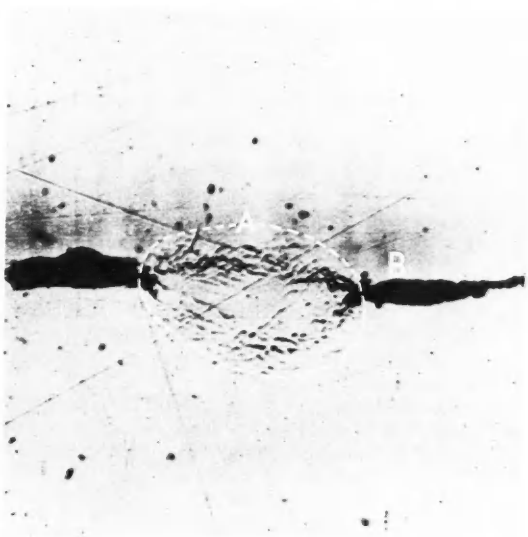


FIG. 2. Photomicrograph of the surface of armour-plate steel which has been stressed in tension, showing the stress-raising action of inclusions and fine cracks. In this instance the increase in the local stress has resulted in large plastic deformation in region A; B is an inclusion.

(Reproduced by courtesy of the Director of N.P.L.)

FIG. 3. Photomicrograph (×6) of part of a turbine blade which has failed from fatigue. The step-like progress of the fatigue crack—which started at *X* and has resulted in the shell-like markings—is clearly illustrated on the fractured surface.

amount of movement as would occur in static tests, the fact that, unlike the latter, it is not all in the same direction, results in the deformation being much less apparent. This explains the brittle appearance of fatigue fractures.

This theory does attempt to explain fatigue by those factors which are known to operate in static loading. But recent investigations, employing x-ray crystallography, have indicated metallographic differences between the effect resultant from dynamic and static loading. Further, it would appear that these differences become more apparent as the frequency of stress application is increased.

If, however, fatigue is a result of local deformation—work-hardening and crack formation in that order—by regularly interrupting a fatigue test and completely annealing the specimen on each occasion, the work-hardened metal should be converted to its initial soft and plastic form, and the completely brittle condition which precedes crack formation thereby prevented from occurring. Thus by this treatment, even with a load in excess of the fatigue limit, crack formation and resultant fatigue failure should be avoided. Experiments have shown, however, that ten such heat-treatments during a fatigue test did not increase the life of a normal sample. This would imply that either a crack formed very early in the test, before the heat treatment was applied, or that some special kind of damage could be caused by dynamic loading which, unlike that in static loading, was impervious to heat treatment.

It has been found that if at the beginning of a fatigue test, the specimen is subjected for a short time to a very light fluctuating stress well below the fatigue limit, then the ultimate fatigue resistance is increased. The metal seems to be able to train or condition itself to "take" fatigue. Conversely, subjecting the specimen to a stress well in excess of the fatigue limit for a short time, results in some damage within the metal, which lowers the fatigue resistance.

Very probably, the beneficial result of initial light stressing is due to a work-hardening and toughening action in the metal adjacent to inclusions. The harmful effect of over-stressing, however, and the reported lack of response to heat treatment suggests that a deterioration is also taking place within the metal and this is the factor which is the "missing link" in fatigue.

When considering this subject, it must be remembered that metals may be stressed by indirect means. For example resonance from sound waves, besides inducing fundamental vibrations, may cause harmonic vibrations which result in very high local stresses.

When metals are suspended and struck, they emit a ring. Different metals vary in the duration of the ring—or vibrational decrement. No matter how carefully extraneous influences are avoided, metals always damp out the vibrations and the ring dies away. Mechanical energy is put into a metal when it is struck—since the induced vibrations then die away, this implies that the mechanical energy is converted to another form. Part, at least, will be transformed to heat. But does the residue contribute in some measure to the ultimate rupture of a metal? It has been suggested that metals behave in fatigue in accordance with their damping capacity. Certainly when failure from fatigue is imminent, a marked increase in damping capacity has been observed. This, however, may result from incipient crack formation.

At present, although we know how to design and treat a metal so as to assist it to resist fatigue, the basic question—what is the cause which leads to the effect of a fatigue crack—still remains to be completely explained. The vital importance of this subject, however, fully justifies the present research in government and industrial laboratories which we hope will ultimately assist in the construction of stronger, safer, and more durable structures in alloys known and yet to come.

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PROGRESS IN ELECTRONICS

Many of the fantasies of science fiction writers are being brought nearer to reality by a new invention known as a transistor. This is a tiny device which has a similar function to a radio valve, but which operates on an entirely different principle.

The basis of the transistor is purified germanium, an element whose peculiar properties permit the close control of the movement of electrons within its structure. In this respect it differs from the radio valve in which electrons are controlled within a vacuum.

The transistor needs no filament and operates at very low voltages and currents. This means that its power consumption is negligible, and it is very economical to use. Another advantage is its small size—in many cases no larger than a pea—which is opening up applications hitherto impossible with the conventional valve.

Mullard transistors are already being used extensively in hearing aids where their small size and low power requirements are resulting in instruments of match-box dimensions, which will operate for about three hundred hours from one miniature 1.5 volt battery.

Transistors are also being successfully employed in the development of equipments as diverse as computing machines (electronic brains) and portable gramophones, telephone equipment and nuclear radiation counters. And this is only a beginning. Research continues, and it is still impossible to foresee the ultimate extent of transistor applications, although potentially they appear to be unlimited. Whatever the future may bring, the Mullard organisation will play its traditional part in supplying British equipment manufacturers with electronic devices of the most advanced design and the highest quality.

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NATURAL AND SYNTHETIC POLYELECTROLYTES

B. E. CONWAY, Ph.D., D.I.C., A.R.C.S.

Assistant Professor of Physical Chemistry, John Harrison Laboratory of Chemistry, University of Pennsylvania, Philadelphia

Wöhler's synthesis of a biological natural product—urea—in 1828 eliminated the central dichotomy of chemistry, and since then the advances of synthetic organic chemistry, biochemistry and colloid chemistry have steadily made the boundary between the non-living and the organic living world more diffuse, at least from a chemical point of view.

The foundations of the physical chemistry of macromolecules were laid in classical colloid chemistry. The latter was mainly concerned with the properties of inorganic sols, emulsions and membranes, and later of surface films and colloidal electrolytes, which were investigated and described—by Graham, Tyndall, Hardy, Perrin, Langmuir and McBain, for example. The similarity in behaviour of various bio-colloids to that of classical colloids tended to obscure the differences which existed between them. In particular, while most classical sols consisted of a system of particles of a substance having variable and indefinite molecular weight, many bio-colloids are now considered as individual polymeric chemical species having a much more precise and definite molecular weight and chemical "identity".

Amongst the most important developments in colloid or macromolecular chemistry has been the synthesis of polymers with high molecular weights, analogous in general properties to the bio-colloids. Such syntheses have been achieved by condensation of a large number of simple molecules in a controlled manner. The early systematic work in this field was carried out by Staudinger, and much stimulus was given to the work by the realisation of the similarity of synthetic polymers to certain natural products, e.g. rubber, gums.

OCCURRENCE AND PROPERTIES OF POLYELECTROLYTES

The first work on the type of compounds now known as *polyelectrolytes* was included in Staudinger's studies on polymeric materials, and was extended by Kern.

The term *polyelectrolyte*, introduced by Fuoss, covers that type of polymer which by some ion-producing reaction can become converted to a polymer molecule having a number of electrical charges—*ionised sites*, as they are called—along its length. As their name implies, polyelectrolytes are electrolytic derivatives of polymers, and they have the characteristics of both electrolytes and polymers. Some new properties result from the influence of the polymer chain in confining the charges to a limited volume, even at high dilutions, and from the influence of the charges on the shape of the polymer chain. Two synthetic polymers of this type are polymethacrylic acid and polyvinylpyridine. In strongly alkaline solution the former becomes converted to the negatively charged polymethacrylate ion, essentially by reaction with the solvent (Fig. 1). The latter may be converted to the positively charged polyvinylpyridinium ion by reaction, for example, with strong acids (Fig. 2).

In addition to these polyelectrolytes with charges all of one sign, there can be prepared what are called *polyampholytes* that have both positive and negative charges.

Of these three classes of polyelectrolytes, two occur extensively in nature. Thus pectins in plants and hyaluronic acid in animals are acidic derivatives of polysaccharides (polymers consisting of chains of sugar molecules); ribonucleic and deoxyribonucleic acid salts play a predominant role in the functioning and reproduction of living cells.

Proteins and some polypeptides (substances related to proteins but of simpler structure) provide a wide range of natural polyampholytes which have both positive and negative charges. The proportion between the different charges is determined by the chemical constitution of the protein and whether its environment is acidic or alkaline. Amongst the proteins, one of the most interesting polyelectrolytes is myosin, which occurs in the complex of proteins in muscle and appears to be intimately concerned with the mechanism of muscle contraction. Myosin has essentially the character of a polyampholyte and carries a net positive charge below *p*H of 5·4.

In addition to these polyelectrolytes of biological interest, industrially important materials such as viscose

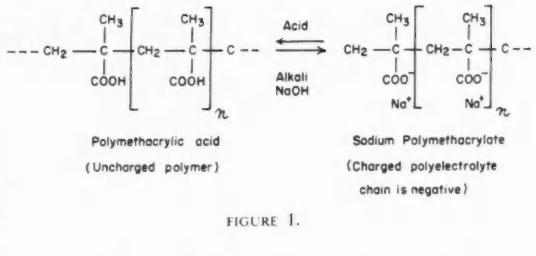

FIGURE 1.

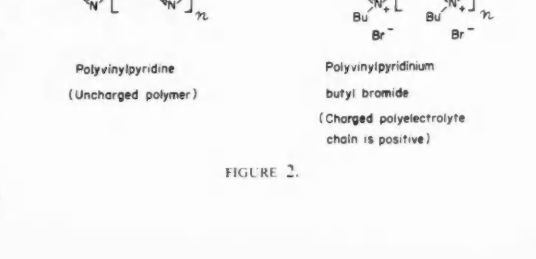

FIGURE 2.

and soil conditioners like Krilium are electrolytes with long chain-like molecules. The ion-exchange resins are polyelectrolytes with linkages running across from one chain to another, and have the property of reversibly binding in their polymeric charged lattice a corresponding quantity of simple ions with opposite charge (technically known as "gegen ions"). These bound ions can be exchanged with ions of another type, but of the same sign of charge, outside the resin lattice.

Wool may be regarded as a kind of potential polyelectrolyte or exchange resin, and on this basis an explanation can be found of many of the phenomena of dyeing.

VISCOSITY OF POLYELECTROLYTES

In physical chemistry, polyelectrolytes are of greatest interest in respect of the new properties which they exhibit, compared with the simple electrolytes on the one hand or uncharged polymers on the other. One of the most striking of these properties is the remarkably high viscosity of their solutions, even at moderate concentrations, compared with those of the uncharged polymer from which they are derived. Thus, in dilute acid solution, polymethacrylic acid of a given molecular weight, e.g. 200,000, has a specific viscosity little different from that of its methyl ester (a completely non-charged polymer) at the same concentration. But if the polyacid is neutralised by dilute alkali its specific viscosity rapidly increases after the degree of ionisation exceeds 10%, reaching a maximum viscosity at a point corresponding to between 50% and 60% ionisation. At these degrees of ionisation the viscosity of the polymethacrylate salt is of the order of several hundred times the viscosity of the polyacid in acid solution. This behaviour is shown in Fig. 3. It is also exhibited by other synthetic polyelectrolytes, including basic ones; in the latter case, however, the increase of viscosity is brought about, for example, by acids. With polyampholytes, e.g. copolymers of methacrylic acid and vinylpyridine or polypeptides, the specific viscosity increases with the increase of both positive or negative charges and is at a minimum at the *p*H at which the net charge is zero.

When polyelectrolytes are in the highly charged condition which gives rise to high viscosity, they are remarkably susceptible to the action of simple salts, even at very low salt concentrations. Thus, a 0·01% solution of 60% ionised polymethacrylate of molecular weight about one million, loses about 20% of its viscosity in a 0·00058% solution of salt and about 98% of its viscosity in a 0·058% solution.

We may ask why is it that such profound changes in the viscosity occur. In order to answer this question we must first of all consider what kind of structure the polymer molecule has in solution. Any synthetic vinyl polymer consists essentially of continuous chains of carbon atoms with more or less regularly spaced side-groups. In the case of the polyelectrolytes we have been considering, these side-groups are the acidic carboxyl groups and methyl groups in polymethacrylic acid, and the basic pyridinium group in the case of polyvinylpyridine. The long chains of carbon atoms are relatively

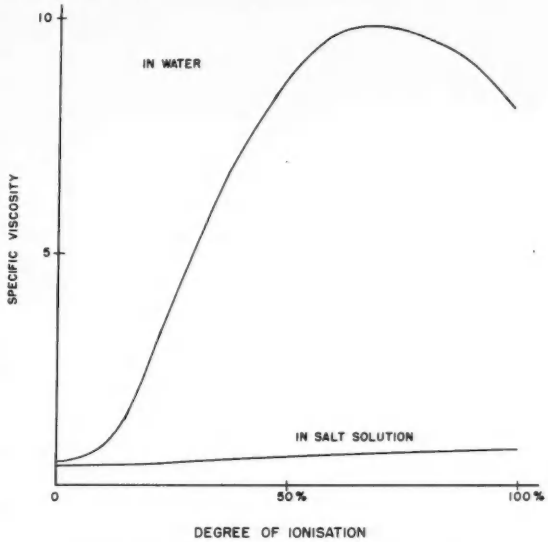

FIG. 3. The upper graph shows the rapid increase of viscosity of polymethacrylic acid upon ionisation by alkali. The other graph shows that the effect is much less in salt solution.

flexible and from a statistical point of view it is very unlikely that any one will at any given moment be in a state of maximum extension. Owing to the effect of thermal agitation or "Brownian motion" at ordinary temperatures, the flexible molecules are continually changing their shape and their extension and these two terms have only a statistical significance. In fact the polymer molecule adopts an average shape of maximum probability or "entropy"; for uncharged polymers this state is one in which the polymer is relatively highly coiled, as in unstretched rubber. When electric charges are caused to exist in the polymer chain by some ion-producing reaction—like neutralisation of a polyacid by sodium hydroxide—the like charges repel each other and this tends to push open the coiled polymer, giving it a greater average extension. Since the viscosity of polymers depends on their length, this expansion of the polymer coil is believed to be responsible for the rapid rise of viscosity resulting from ionisation of polyelectrolytes.

The large effect of salts on the viscosity of polyelectrolytes cannot be interpreted in the same way as for classical colloidal particles. The effect of salts on the viscosity of colloid sols is relatively small and is in approximate accordance with the predictions of a mathematical theory developed by Smoluchowsky and Krasny-Ergen. For polyelectrolytes the effects of salt on their viscosity are far too large to be interpreted by these theories, which are based on the idea that excess simple salts would decrease the viscous drag of the diffuse cloud of ions of opposite sign which always accompany a charged colloidal particle, by diminishing the effective thickness of the cloud.

Until quite recently it has been felt that the marked

FIG. 4. Magnetic model of polyelectrolyte chain fully expanded by repulsion.

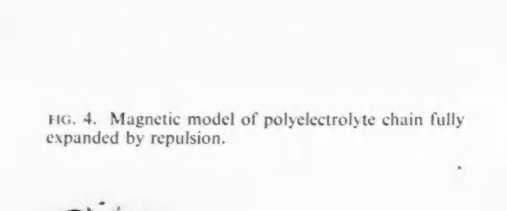

FIG. 5. Magnetic model of polyelectrolyte chain contracted to a coil in presence of single opposite poles—the white corks.

FIG. 6. Strong association of magnet chains by sharing of a polypolar group of three magnets of opposite polarity, at centre of picture. This is the analogue of gelling by polyvalent ions (see Fig. 7).

effect of salts on the viscosity of highly charged polyelectrolytes could be accounted for by a contraction of the polyelectrolyte due to screening of its charges by simple ions of opposite sign. This would lead to a diminished electrostatic repulsion between the charges on the polymer and hence to a diminished average extension of the polyelectrolyte and to a loss of viscosity. On this view, it is necessary to suppose that the screening effect of salt at moderate concentrations is so great that almost all the ionic character of the polyelectrolyte is lost, since the viscosity of the charged polyelectrolyte in excess of salt is equal to, or less than, that of the corresponding uncharged polymer.

MAGNETIC MODELS

The properties of polyelectrolytes discussed above can be clearly demonstrated in a dynamic model in a rather interesting way. The electrostatic effects which lead to expansion and to strong interaction with simple ions of opposite charge, are dependent upon a fundamental law of electrostatics, Coulomb's law.

This states that $F=\frac{e_1.e_2}{\varepsilon r^2}$, where F is the force between two charges e_1 and e_2 separated by a distance r in a medium of dielectric constant ε. Now interactions between magnetic poles obey a precisely similar law. If a model of a polyelectrolyte chain were made by floating thin but powerful magnets, with all like poles uppermost, in corks joined by a thread, the repulsion between the magnets should simulate the repulsion between the charges on a polyelectrolyte. The model would formally be an exact replica of a polyelectrolyte in solution if isolated magnetic poles could be obtained and if Brownian motion of the chain of poles could be introduced. If the magnets are long and are closely spaced in the chain the repulsion of like poles at top and bottom of the floating chain is much greater than the diagonal attraction of unlike poles, and the system approximates quite closely to a line of isolated like poles or charges. Brownian motion can be simulated by agitating the liquid on which the magnet chains are floated.

When such a model is made with about twenty or more units, and floated on water, it immediately expands to as long a length as possible, determined by the length of thread used in joining the magnets. This behaviour is shown in Fig. 4, and is precisely analogous to the expansion of a polyelectrolyte upon formation of the charge—as, for example, when a solution of polymethacrylic acid is made alkaline. If floating single magnets of reversed polarity are introduced they tend to accumulate near the expanded chain of magnets and to associate with it. The immediate effect of this is to screen the magnetic poles on the chain and to collapse the extended chain into a compact coil. In fact, the single magnets diminish the repulsion within the chain and also give rise to local attractive effects between two or three adjacent "polymeric charge units" on a given chain, pulling these charges nearer together than they might otherwise be. The effects of added single magnets are

shown in Fig. 5, and are analogous to neutralisation of the polyelectrolyte charges, for example by strongly acidifying a polyacid salt. More strictly, the effects are comparable to those of added simple salt on a charged polyelectrolyte molecule. Here the excess of simple ions screens the charges in the chain and diminishes their repulsion; hence the molecule contracts. Some extreme coiling of polyelectrolytes in salt solutions has been observed, and this is also the behaviour found with the magnetic model when local attraction between a single magnet and several units of opposite polarity in the chain occurs as described above.

In aqueous solution, ions of simple electrolytes show little tendency to pair or to form clusters, since individually the interaction of their ions with the water is stronger than the interaction of the ions amongst themselves. With polyelectrolytes, however, the very strong electrostatic field of the charged polymer causes strong attraction between the simple ions of opposite charge to the polymer and the charged polymer itself. This is clearly shown when properties of the polyelectrolyte system as a whole—a charged chain plus the equivalent number of oppositely charged simple ions—is studied. Thus for sodium polyacrylate, Wall was able to show very elegantly, by the use of radioactive sodium as a "tracer" that positive sodium ions were actually transported in part to the positively charged *anode*—whereas normally they would go to the cathode—when electrolysis of a solution of the polyelectrolyte was carried out. This effect was due to the strong association of the positive sodium ions with the polyvalent anion. Several other types of experiment lead to the same conclusion. The magnetic models, e.g. Fig. 5, clearly show this type of effect in operation. With a polypolar group of magnets, analogous to a polyvalent ion, the interaction is very strong indeed (Fig. 6). Again, this is what happens with polyelectrolytes themselves; addition of polyvalent cations to strong solutions of negatively charged polyelectrolytes precipitates them or causes them to form thick gels by a kind of electrostatic cross-linking, as shown in Fig. 7. From the models, it is also possible to see that some local attraction between the magnet chains occurs as a result of single independent poles being simultaneously attracted to two or more chains. There is some evidence, we shall see later, that this kind of effect probably also occurs in real solutions of polyelectrolytes and is partly responsible for their anomalously high and peculiar viscosity, which diminishes as the rate of flow of their solutions is increased—an effect which we call "non-Newtonian" viscosity.

Although viscosity measurements on polyelectrolytes are very easy to carry out, the interpretation of the results is not proportionately simple, partly because of the limitations of existing theories of the viscosity of these substances. In general, it is possible to interpret viscosity measurements in terms of the existing theories, only if measurements can be obtained which refer to individual polymer particles. Such data can be obtained only if interaction effects are eliminated; this can usually be achieved only by working at very high

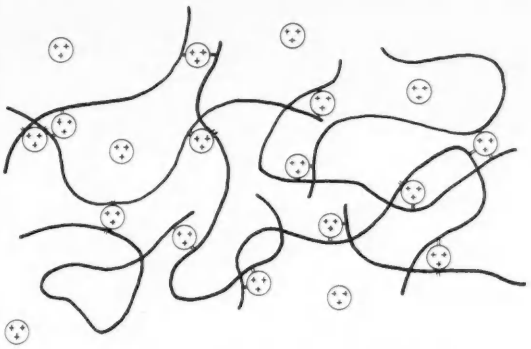

FIG. 7. Diagrammatic representation of a gel of acidic polyelectrolyte formed with polyvalent cations by "electrostatic cross-linking".

dilutions. Pouyet, Conway and Butler were the first to apply this procedure to polyelectrolytes and by use of very sensitive instruments, concentrations of polyelectrolytes as low as 3×10^{-6} grams per cubic centimetre were studied. At these low concentrations, and at very low rates of shear, it is possible to deduce by a process of extrapolation what the viscosity would be at zero concentration and zero rate of flow. Hence we can arrive at a quantity known as "intrinsic viscosity" which is characteristic of the dimensions of the polymer molecule itself.

With nucleic acid, one of the most striking results obtained was that although simple salts strongly affect the viscosity of the polyelectrolyte at moderate concentrations, their effect diminishes relatively rapidly as the solution becomes more dilute. At "infinite" dilution of the nucleic acid, salt has little or no effect on the intrinsic viscosity of the deoxyribonucleic acid and hence on its molecular dimensions. In view of the supposed contractile properties of polyelectrolytes this result was surprising. However, recent x-ray diffraction studies by Watson and Crick on the structure of deoxyribonucleic acid indicate that it has a remarkable twinned helical structure composed of two complementary halves held together by hydrogen bonds (*see* Fig. 11). Unlike that of most synthetic polyelectrolytes, such a structure is fairly rigid and cannot easily be made to coil up. Thus, even in the presence of salts, the nucleic acid molecule still retains its rod-like structure.

The present author showed that when the nucleic acid is treated with a strong solution of urea (which is known to split hydrogen bonds) a product is obtained which no longer is such a rigid molecule because a definite effect of salt on the length of the molecule could be demonstrated; at the same time the molecular weight was approximately halved. These results seem to support the x-ray diffraction evidence that the structure of deoxyribonucleic acid is a double polyelectrolyte chain held together by hydrogen bonds.

If the intact molecule of nucleic acid does not contract in the presence of salts, we must suppose that the marked effect of salts on the viscosity of nucleic acid at

FIG. 8. Association of single poles (white corks) with two chains leading to interaction between the two chains (black corks) by sharing of a single pole of opposite polarity (left centre of picture).

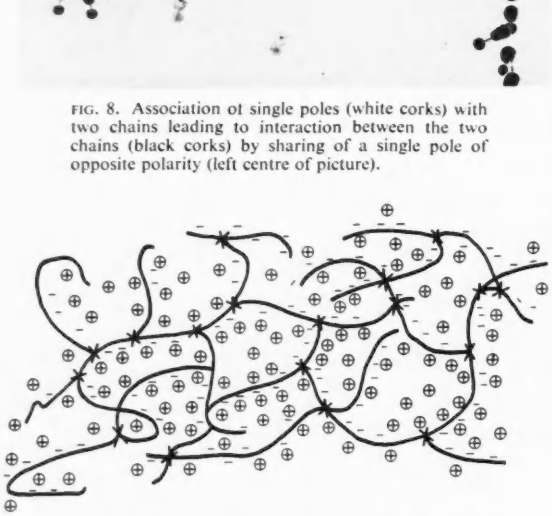

FIG. 9. Diagrammatic representation of an ionised cross-linked polyelectrolyte gel. × = points of cross-linkage.

higher concentration is due to an effect on the electrostatic interaction of the highly charged elongated particles. With synthetic polyelectrolytes, such as polymethacrylic acid and polyvinylpyridiniumbutyl bromide, this effect is responsible also for a considerable proportion of the high viscosity of the solutions at moderate concentrations. Studies with these polymers at very low concentrations, however, indicate that there is still a measurable contraction of the polymer molecule in the presence of excess of simple salts, as predicted by various theories of polyelectrolytes. The interaction effect in polyelectrolyte solutions can be demonstrated by the magnetic models. Thus, if we float several chains of magnets amongst several single floating magnets of opposite polarity it is seen that there is a net local attraction between the single magnets and the various "polymer" chains (Fig. 8). This could in practice give rise to an increase of viscosity, since extra forces would have to be applied to shear the liquid in order to overcome the attractions amongst the chains and their associated ions. If the ions are di- or poly-valent, the interaction forces are very strong and formation of gels might be expected (Figs. 6, 7), and this has been observed experimentally. The existence of repulsive electrostatic forces amongst polyelectrolyte particles has been suggested, and this type of interaction amongst the particles could also lead to an enhanced viscosity. At the moment it is difficult to decide which are the forces operative in causing the large amount of interaction which exists in polyelectrolyte solutions. However, the forces of interaction in simple electrolyte solutions are definitely attractive, and it is difficult to see why the forces in polyelectrolyte solutions should be of an opposite kind. While it is not always safe to draw conclusions from the behaviour of models, it is of interest that the magnetic models indicate a net local attractive effect in a system consisting of chains of poles and independent single poles of opposite polarity.

MECHANO-CHEMISTRY

We may inquire if the reversible expansion and contraction of polyelectrolytes upon ionisation, or neutralisation of the electric charges, is also exhibited in macroscopic systems. By building up polyelectrolyte molecules into a visible "infinite molecule"—such as a gel in which the polyelectrolyte molecules are all joined together by cross linkages (Fig. 9)—it is easily possible to see the expansion effect which results from ionisation. Such gels were first made by Kuhn and Katchalsky and others by cross-linking polyacrylic acid with polyalcohols and by phosphorylating cross-linked polyvinyl alcohol. When these gels are ionised by addition of sodium hydroxide all the molecules expand in a co-operative way. Since they are all joined together in the

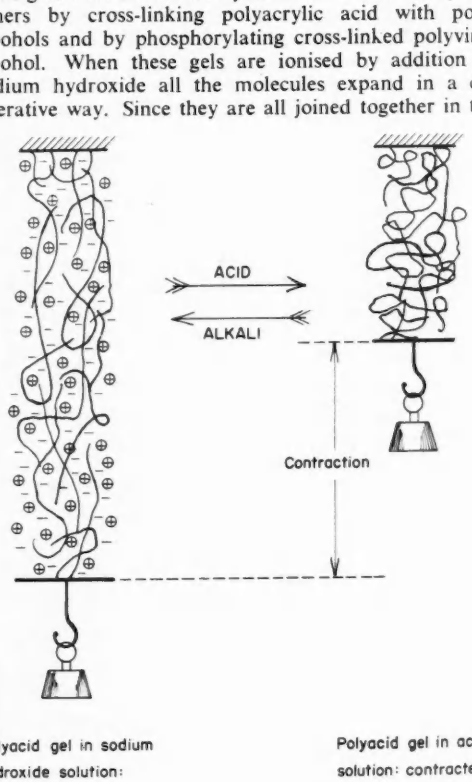

FIG. 10. Expansion and contraction of a polyelectrolyte gel.

gel, a visible expansion of the gel occurs, and this can be reversed by addition of acid; the process can be repeated at will.

Two important aspects of this work were soon obvious to those working in the field. First, the reversible mechanical effect might be used in a kind of chemical engine, because these materials have the unique property of converting chemical electrostatic energy into mechanical work in a more or less reversible way. In fact, it is already possible to produce fibres of polyelectrolyte gels and to make them lift small weights by, for example, neutralisation of their charges with acid (Fig. 10).

Secondly, this so-called "mechano-chemical" effect appeared to be remarkably similar to that involved in the contraction of muscle, a phenomenon whose mechanism has puzzled chemists, biologists and physiologists for a long time. From what we know of the chemical nature of one of the constituents of muscle, myosin, it seems that this compound is a very long protein molecule carrying ionised, or potentially ionisable, groups as in a polyelectrolyte gel. It seems likely that, by some co-operative enzyme reactions, the electrostatic energy of these molecules is suddenly diminished, in a muscle twitch, by a change of charge or chemical environment of the molecules of myosin in muscle; consequently, as with polyelectrolyte gels, a contraction is caused. Whilst the details of the chemistry of this process are not yet fully known, the discovery of mechano-chemical effects with polyelectrolyte gels has helped considerably in the understanding of muscle action.

POLYELECTROLYTES OF BIOLOGICAL ORIGIN

Naturally occurring polyelectrolytes such as pectins or deoxyribonucleic acid show in a general way a remarkable physical similarity to synthetic poly-acids. They have many properties in common, e.g. high molecular weight, high charge-density, large degree of asymmetry of their molecules, so it is not surprising that their viscosities at a given concentration are similar for approximately the same molecular weights. They show a similar non-Newtonian viscosity. However, despite these similarities, detailed work on the comparison of certain natural and synthetic polyelectrolytes has revealed differences of behaviour which can be interpreted in terms of the possible structures of the compounds concerned. Particular mention has been given to the properties of deoxyribonucleic acid; this occurs principally in the nuclei of cells, where it is bound to basic proteins of low molecular weight. Much evidence exists that the nucleic acid is a biologically active component of the chromosomes of the cell nucleus, which determine the hereditary characteristics of the organism. One of the most striking properties of certain nucleic acids is their ability when in a pure form —uncontaminated, as far as is known, with proteins or polysaccharides—to transform certain types of pneumococcus into another form, of the type of that from which the nucleic acid was originally extracted. This effect is

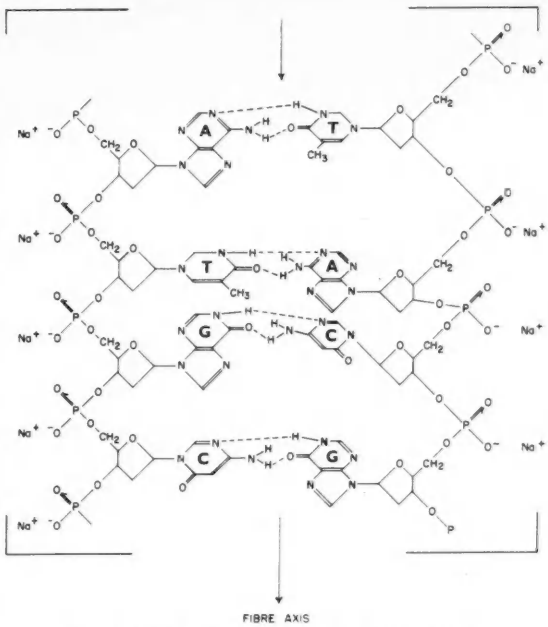

FIG. 11. Partial formula of double polyelectrolyte chain in deoxyribonucleic acid. The order of purine and pyrimidine groups is unknown but it is likely that Adenine (A) is always paired with Thymine (T) and guanine (G) with cytosine (C). This pattern is repeated along the axis of the fibre about 10,000 times.

as though the nucleic acid were acting in a genetically determinative way towards the organism treated with it, i.e. as if the nucleic acid itself were a kind of isolated gene.

The high viscosity of nucleic acid solutions of quite low concentration, e.g. 0·01–0·1%, has provided a useful physical method by which to follow reactions involving nucleic acid. For example the action of the substance $CH_3N(CH_2{-}CH_2Cl)_2$, a nitrogen mustard, on nucleic acid has been studied viscometrically and the effects of x-rays have been studied in the same way. Their effects on nucleic acid are of particular interest, since these and related agents are known to have a growth-inhibiting action on rapidly dividing cells and to cause genetic mutation, for example in *Drosophila*, and abnormal appearance and behaviour of chomosomes during cell division. It has been the reasonable supposition, which is now receiving increasing support from various kinds of work, that the deoxyribonucleic acid polyelectrolyte present in the chromosomes, is one of the components of the nucleus intimately involved in the biological effects of radiation and of chemical agents having similar effects. *In vitro* experiments have indicated that chemical compounds like the nitrogen mustards act in two ways. First, they combine with the

NH_2 and OH groups of the purines and pyrimidines of the nucleic acid, and they also combine partly with the phosphate groups in the nucleic acid (Fig. 11); subsequently the original polymer slowly breaks down into smaller fragments. With x-irradiation a variety of effects occur, amongst which are oxidation and fission of the polymer chain, leading to immediate partial depolymerisation. Some other effects also occur, causing breakdown of the polymer after the x-irradiation. This latter effect is much enhanced by the presence of oxygen during the irradiation; this is rather similar to the enhancement of radiation damage which is observed when bacteria and other organisms are irradiated in oxygen.

In addition to intramolecular interaction in polyelectrolytes of biological origin, e.g. myosin, it is of interest to note that certain interactions between polyelectrolytes of opposite charge appear to be important in some biological processes.

This kind of interaction occurs between proteins in the cell cytoplasm, between deoxyribonucleic acid and basic proteins (histones and protamines) in the cell nucleus, hyaluronic acid and collagen in connective tissues. Acid base polyelectrolyte interaction is also the basis of certain biological defence mechanisms against intruding micro-organisms. This was demonstrated in a convincing way by Bloom and Cromartie who showed that the anthrax bacillus excreted polyglutamic acid, a negative polyelectrolyte, which is counteracted *in vivo* by a factor derived from the leucocytes. This agent is a positive polyelectrolyte and combines with the negative polyelectrolyte, which is removed as a jelly-like precipitate. Such interactions can easily be demonstrated in the test-tube and their mechanism is readily understandable from the magnetic models, which show, of course, a very strong attraction between chains of poles of unlike polarity.

We may hope that the further study of the physical chemistry of polyelectrolytes will enable the vast variety of factors involved in the mechanism and dynamics of vital processes in cells and living matter to be better understood. Already much progress has been made: if it has taught us a little of the details of some biochemical processes it has been invaluable in warning us of the incredible complexities of the chemistry of the living cell in which polyelectrolytes of various kinds figure so prominently.

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CASH BENEFITS FROM RESEARCH

"There is no better national investment than well directed scientific research." This comment of Mr. R. G. Casey, the Minister in Charge of Australia's Commonwealth Scientific and Industrial Research Organisation, fittingly summed up the most interesting statement which he recently made about the cash benefits resulting from the large-scale application of science in his country.

The control of the rabbit plague by myxomatosis was one example he quoted. He said that this was estimated by the Bureau of Agricultural Economics to have been responsible for an increase of £32 million in the 1953–4 wool clip.

The overall increase in primary production due to myxomatosis was estimated at £50 million a year—more than enough each year to pay for the whole cost of C.S.I.R.O. (£33 million) in the whole thirty years of its existence. Moreover, this increase in productivity continues each year in the future.

Australia has invested a good deal of effort in developing biological control of noxious weeds, the most spectacular example of which has been the eradication of the prickly pear cactus from vast areas. Mr. Casey mentioned the elimination of an impenetrable jungle of prickly pear from 60,000,000 acres in northern New South Wales and Queensland which made possible the restoration of this land to agricultural and pastoral production. He said that the value of production from this reclaimed land must now be worth at least £50 million a year.

Mr. Casey's comment quoted above is a good deal more than just an expression of personal opinion. His view that the C.S.I.R.O. is one of Australia's most profitable investments has been official government policy for a long time. Expenditure on the C.S.I.R.O., which is Australia's equivalent of Britain's D.S.I.R., is relatively lavish. This organisation, which was started in 1926, has an annual budget of around £5 million.

WHAT USE ARE PLANT PATENTS?

The argument that new plant varieties should be given protection by patent legislation has some supporters in Britain. The patenting of plants has been possible in the U.S.A. for twenty-five years, and one or two other countries have followed the American lead. This article by a Chartered Patent Agent considers how far experience justifies the belief that such a system of patent protection would encourage the breeders of new varieties of plants.

The British law on Patents for inventions is based on the Statute of Monopolies passed in the reign of James the First (1628). This statute declared monopolies such as had been granted by Royal Letters Patent to be unlawful, but excepted the limited monopolies granted to inventors, in the following terms:

> Provided also that any declaration before mentioned shall not extend to any letters patent and grants of privilege for the term of fourteen years or under hereafter to be made of the sole working or making of any manner of new manufactures within this realm to the true and first inventor and inventors of such manufactures . . .

The term of fourteen years has since been increased to sixteen years but patents are still only granted for manners of new manufactures. A long series of legal decisions has gone to determine what is and what is not a "manner of new manufacture". It can be said that the term covers manufacturing processes, machines and manufactured articles, including chemical products, but does not include any "manner of new agriculture".

For very many years the patent laws of other countries, though expressed in different terms, protected inventions of similar scope. The exclusion from protection of agricultural or horticultural processes and products has often been felt as unfair to those branches of the arts. The patent system has encouraged progress in industry, and some people argue that by analogy progress in agriculture (or to put it more widely, in bioculture) would also be fostered by the granting of patents in that field.

That argument was accepted as valid in the U.S.A. where in 1930 the Legislature extended the Patent Law to authorise the granting of Plant Patents.

The Patent Law of the U.S.A. now states:

> Whoever invents or discovers and asexually reproduces distinct and new variety of plant, other than a tuber propagated plants, may obtain a patent therefor.

Such patents are on the same footing as patents for industrial inventions, and are granted for the same period, namely seventeen years.

Very recently the Union of South Africa followed suit and extended her Patent Law in almost exactly similar terms.

As the introduction of Plant Patents into the United Kingdom Law has been raised from time to time, it is of interest to examine whether the law in the U.S.A. has had the expected effect and so obtain some guide as to whether it would be of benefit to the United Kingdom to follow the American example.

A writer in the U.S.A., welcoming the new provision in the Patent Law, made the following comment in 1931:

> The new law will undoubtedly encourage many original workers in the field of horticulture, for it gives the plant breeder the same status as the inventor of a new machine, alloy or dyestuff. . . . The remarkable advance in our industries has been largely caused by the granting of patents. . . . The plant breeder now has similar privileges and he can protect his new creations just as the mechanic can protect his new machine by obtaining a patent.
>
> (*Journal of the Patent Office Society*, Jan. 1931, p. 10.)

Yet the records show that during the years 1945–54 the average number of applications for Plant Patents in the U.S.A. was only seventy nine per year, as compared with the average of 68,021 per year in the general, mechanical, chemical and electrical arts. These figures scarcely indicate that the hopes of the writer quoted above have been realised, or that this provision of the law has been an unqualified success. It appears desirable to examine the reasons for this.

A writer in the *Journal of the Patent Office Society* (April 1953) has attributed this lack of success to the fact that the provision of the law is limited to the protection of plants that are propagated asexually and has urged that it should include the protection of seeds and of plants propagated by seeds. This seems singularly unconvincing; only if the law had proved successful in its limited scope could its extension to a further scope be justified.

The administration of the law regarding this class of patents involves certain difficult problems. There is, for instance, the difficulty of drawing up a satisfactory specification. The Patent Laws in the U.S.A., as in the United Kingdom and most other countries, require the filing of a specification which describes the invention and formulates clearly in a claim or claims the method or article from which patent protection is sought. These claims are subjected by the Patent Office to an examination for clarity and novelty and only when the applicant has formulated claims which are considered to define clearly a novel invention is the Patent granted. (In the case of patents in the industrial arts it is often the case that several attempts are necessary before the final form of the claims is settled to the satisfaction of the Patent Office.)

The ultimate value of a patent can only be tested fully by the willingness of someone to pay a royalty for the use of the patented invention. This willingness is enhanced if there is general confidence that patents are likely to be granted only for worthwhile inventions. This confidence is enhanced by the fact of a severe examination in the Patent Office and the opportunities offered thereby for amending the claim in response to criticism and in the light of the prior knowledge brought to light in the course of such examination. This affects the prestige enjoyed by patents and the extent to which inventors are encouraged to apply for patents for their inventions.

Great difficulties are encountered when one has to describe exactly a new variety of plant, and also when a Patent Examiner has to examine such a description to make sure that it correctly defines the novelty of the new variety. In the case of an application for a Plant Patent in the U.S.A. the specification is required to contain a complete description of the new variety of plant, and in most cases it must be accompanied by a coloured drawing. The claim must refer to the description and must summarise the point or points of novelty.

The claim of a typical and fairly recent U.S. Plant Patent (No. 1335) is as follows:

> A new and distinct variety of rose plant of the hybrid tea class, substantially as herein shown and described, characterised particularly as to novelty by the combination of its relatively large flowers of amber yellow general color tonality, its upright, free and vigorous growth, its relatively stiff stems, its semiglossy foliage and the retention of its flowers in hot weather when grown under glass.

Having regard to the difficulties involved in formulating a verbal description in simple language, the above is probably the best the applicant could do, but it would appear to fall far short of a description sufficiently precise really to distinguish the new variety from numerous others. It would appear from the general run of the claims in U.S. Plant Patents that the American Patent Office has never succeeded in achieving the rigorous kind of examination which one associates with other types of patents.

These difficulties were foreseen right at the outset. Thus we find the following comment by an expert was published in the *Journal of the Patent Office Society* when the U.S. Plant Patent law first came into force:

> When the majority of pomologists frankly admit that they cannot begin to differentiate the existing varieties of apples, the utter impossibility of relying upon verbal descriptions, or even on drawings or photographs, begins to be evident.

This expert thought that the furnishing of a type plant would be an absolute necessity in the patenting of new varieties. The Union of South Africa has evidently taken the same view, for it has enacted that an applicant for a Plant Patent must supply two samples of the new variety of plant so that it may be grown and studied in a Government Botanic Garden.

Such samples should certainly get over the difficulty of establishing the exact nature of the new variety of plant and the determination of whether or not it really is a new variety. But on the other hand it imposes a very heavy burden on the applicant for a patent in that it forces him to part with some of his scanty and therefore probably very valuable stock. This point can be appreciated if one realises that a new daffodil of merit, for instance, may fetch as much as £100 per bulb when first placed on the market; in such a case the enforcement of this condition would mean that the applicant would have to furnish samples equivalent in value to £200.

Apart from difficulties of administration, however, the whole concept of Plant Patents appears to be based upon a false analogy with patents for inventions in the mechanical and chemical arts. A patent for an invention for a manner of new manufacture is not granted merely, nor even primarily, as an award for having invented something. The specification filed to obtain such a patent must describe not only the new invention for which the protection of a patent is desired, but also the way in which this invention is to be carried out in practice. In this way the sum of human knowledge is increased; the way in which the invention is carried out is published in such detail that, after the expiry of the patent, the invention can be practised by anyone. It can be said that the filing of such a description is one of the essential considerations in return for which a patent is granted.

Publication of a specification of this kind is the only effective way of securing that knowledge of the invention is not lost but becomes part of the general background of the branch of industry concerned. A new or improved process is very likely to be lost if a description of it is not given to the public in this way. A knowledge of the construction of an article or of a machine may perhaps be gathered from a surviving specimen, but specimen articles or machines, if only available in small quantities, might, however, easily be lost or destroyed. Machines or articles of manufacture can only be reproduced by each one being built afresh by a process substantially the same as the process by which the first such new article or machine was built.

This difference between an article of manufacture and a living plant is fundamental in considering the relative value to the public at large of patents for manners of new manufacture and Plant Patents.

As plants are propagated by processes within the skill of any gardener, it is not necessary nor in general useful that the process by which a new variety was brought into being should be described in order that the public should enjoy whatever benefit the existence of the new variety may confer. The specification of a patent is supposed to enable anyone skilled in the art to reproduce the inventor's results, but in the case of a Plant patent this does not apply at all. There is no description of the "creation" of the new variety, and even if this description were given it would be useless to the public. It follows also that the reasoning whereby it is deduced that Plant Patents are of benefit to horticulture, because patents for manners of new manufacture have been of benefit to industry, is fallacious.

The call for Plant Patents has no doubt been due to a feeling that methods of bioculture should be protected by patents. It should not be overlooked that some methods of bioculture are in fact already so protected. Many processes of manufacture of chemical compounds depend upon fermentation by specific strains of bacteria and the manufacture of such drugs as penicillin involves large-scale cultivation of moulds. Thus to the extent that a method of bioculture forms a manner of new manufacture it can be protected by a patent under the existing law.

There are only historical and no logical considerations why a patent can be granted for one form of bioculture and not for another. Indeed if logic were to be applied to the subject some patents for manners of new manufacture dependent upon bioculture would not be granted. Such is the case where, for example, a fermentation process depends upon a particular strain of bacteria discovered by the inventor, which can be termed a new variety of bacteria in that it possesses desirable fermentation properties to a greater degree than any previously known strains. The patent specification in such a case does not enable the public to practise the so-called invention in the absence of possession of some of the bacteria of that particular strain, and the description of the characteristics of the strain does not enable a bacteriologist to isolate the new variety for himself.

I have heard a rumour that the Government of Western Germany is contemplating the extension of the patent law there to cover methods of agriculture or horticulture described in such terms as to enable the reader of the specification to follow such methods. If this be true it points to a direction in which the patent law could lead to advances in the biological arts comparable to the advances in industry hitherto encouraged by the patent laws of that and other countries.

TITANIUM: THE JET-AGE METAL

Titanium is once more in the news. Imperial Chemical Industries have now started their first large-scale production of titanium sponge, using a new method to supplant the Kroll process. The new I.C.I. plant is scheduled to produce 1500 tons of this remarkable metal a year, and a reduction of the present price (over 30 shillings per pound) may be anticipated.

The new method involves the use of liquid sodium as the reducing agent instead of magnesium, in the production of titanium metal from titanium tetrachloride. Titanium sponge is the tough, sponge-like mass of metal left in the reacting vessel after the other products of the reaction have been distilled off. It has to be chipped out and cast into ingots in specially designed furnaces which prevent the metal dissolving the walls and absorbing atmospheric gases.

Discovered in 1790 by an English clergyman, the Rev. William Gregor, titanium has emerged as a key metal in this age of jet aircraft. Its rise to importance in the metallurgical world has been unprecedented, for demand has consistently exceeded supply ever since its potentialities were recognised. The production figures in America over the last few years illustrate this point. The annual output soared from 2 tons in 1947 to 5000 tons in 1954.

The reason for this sudden interest is that titanium and its alloys, with tensile strengths from 50 to 70 tons per square inch, are as strong as most alloy steels while being only half as heavy. This high strength/weight ratio is retained up to 500°C when the metal starts to react with atmospheric gases. However, one well-established alloy of titanium containing 36% aluminium resists oxidation up to 1100°C, and research into other alloys offers promise in the same direction. Titanium has a high melting point—1720°C, which is about 200° above that of ordinary steel.

Titanium has a corrosion resistance comparable with that of platinum, due to the rapid formation of a hard, non-porous oxide film a few dozen Ångströms thick, which insulates the metal from gases or chemicals.

The use of this metal in aircraft is becoming more and more widespread, since its strength at high working temperatures makes it suitable for such parts as gas-turbine compressor blades, exhaust nozzles, engine nacelles and wing leading edges—parts where normal metals rapidly fatigue or break down. The advanced stage that titanium technology has already reached is evidenced by its extensive use in the new Bristol *Britannia* aircraft.

When all the metallurgical problems have been solved, titanium should find widespread application throughout industry. Almost unlimited supplies of the element are available in the earth's crust. Titanium is the ninth most abundant element and the fourth most abundant metal, being exceeded only by iron, aluminium and magnesium.

Hitherto America and Japan have had a monopoly in the production of titanium sponge. Both countries are expanding their production rapidly—the Americans hope to reach 20,000 tons a year by 1956, and the Japanese, with a present output of 2000 tons per annum plan to reach 10,000 tons by 1958. Canada has entered the market and Russia is also producing the metal in unknown quantities. The cost of American titanium is 3·95 dollars a pound but the Japanese hope to bring their price down to 2 dollars a pound. These figures are for the raw titanium sponge, and processed titanium costs considerably more. While the price remains as high as this titanium will continue to be used only for special purposes, but the costs of production are falling as new techniques are perfected and greater quantities of metal are produced. The new plant built by I.C.I. is a great stride forward and launches Britain as a serious competitor in the world markets.

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A recent American book, *Titanium in Industry*, by S. Abkowitz, J. J. Burke and R. H. Hiltz gives technical details about many aspects of the metal including production, subsequent processing and properties. This 244-page work is published in Britain by Macmillan at 36*s*.

In 1953 we published an article entitled "Titanium" by S. W. Rowell and E. Swainson of I.C.I. (DISCOVERY, vol. 14, pp. 108–12). At that time I.C.I. was developing the sodium reduction process, which remained a well-guarded secret until comparatively recently.

RECENT ADVANCES IN DATING THE PAST

R. N. C. BOWEN, Ph.D., B.Sc., F.G.S.

From the earliest times attempts have been made to date the remote past with special reference to the age of the earth and the antiquity of mankind. The estimates of ancient peoples, based upon tradition and myth, were far too small, and as late as the 18th century it was commonly believed that the earth originated within the last few thousand years. Bishop Ussher assigned the event to the year 4004 B.C. It was James Hutton who first found it necessary to disregard such restrictions in order to make possible his view that geological agencies have acted in the past with the same general intensity as at present.

This doctrine of uniformitarianism evoked extraordinarily bitter feelings, conflicting as it did with both ecclesiastical and secular opinion. During the ensuing controversy, William Smith, a civil engineer concerned with surveying routes for canals, discovered that lithological divisions could be identified by their contained fossils and hence that a fossil succession exists. Subsequent investigations enabled the relative ages of strata to be determined and in 1841 John Phillips proposed the three terms Palaeozoic, Mesozoic and Cainozoic for the fossiliferous geological eras.

Studies on the rates of transportation of sediments by rivers showed that very long periods of time were required for the accumulation of various formations. The Chalk may be cited as an illustration. The Thames carries seawards approximately 500,000 tons of dissolved mineral salts every day, more than two-thirds of this being calcium bicarbonate derived from the limestone outcrops in the drainage basin of the river. The area of these being known, it is an easy matter to calculate that their surface is being lowered by solution at a rate of one foot in 150,000 years. Were this material to be deposited over an area of the sea-bed equivalent to that from which it was eroded, the rate of deposition might also be one foot in 150,000 years. Since the Upper Chalk alone attains a thickness of more than 1300 feet in the Isle of Wight, it is obvious that if it was deposited at such a rate, a period of many millions of years must have elapsed during its accumulation.

THE URANIUM METHOD

Such speculation was valuable in so far as it indicated that terms of reference for geological time must be in millions of years. As a result of the discovery of radioactivity, new methods of investigating the ages of certain rocks were devised and although received with some scepticism at first are now generally accepted. The earliest was that proposed by Boltwood in 1907 and depends upon the amount of lead formed in a radioactive mineral by atomic disintegration. Development of the lead method has extended its use to altered as well as unaltered minerals. As most radioactive minerals contain U^{235}, U^{238} and thorium, it is possible to obtain three age determinations, one based upon the ratio between U^{238} and the lead derived from it, the second based upon the radiogenic lead derived from thorium and a third based upon the ratio between the lead derived from U^{235} and that derived from U^{238}. This triple check is important as the most ancient minerals so far examined were formed 2000 million years ago. The agreement found between the three determinations is usually high.

Several limitations restrict the applications of the lead method. The minerals rich in thorium and uranium are normally found in pegmatites. These are coarse-grained rocks composed of alkali-felspar in association with quartz, white mica, etc. They are formed by the freezing of a residuum of a large igneous intrusion. Pegmatites are not common, however, and do not always contain these minerals. However, a number of determinations based upon the method have been made. A Swedish oil shale called the kolm contains about 0·45% uranium as well as a Trilobite suite indicating its late Cambrian age. The result obtained by the use of the lead method was 440 million years. Two age determinations for the end of the early Permian have been made by analysing a specimen of thorite from near Oslo and a specimen of pitchblende from Joachimstal, both giving the same figure of 230 million years. Another specimen of pitchblende of post-Palaeocene Age from Central City in the Front Range, Colorado, was found to be 58 million years old.

OTHER RADIOACTIVE METHODS

Three other methods based upon radioactivity have been used in measuring the absolute ages of rocks.

The strontium method is still being developed and depends upon the formation of strontium 87 from rubidium 87. This is a very slow process—in 900 million years, only 1% of Rb^{87} will have changed to Sr^{87}—and so the method is most useful in determining the ages of ancient rocks.

The radio-halo method depends upon the intensity of the colour produced around particles of radioactive minerals enclosed within other minerals. Alpha-particles emitted from the former disrupt the space-lattices of the host-minerals and deepen the colours of the latter. The strength and continuance of this bombardment is related to the radioactive content of the enclosed material and the length of time involved. The method suffers from several defects. The halos are only found in very old rocks formed more than 900 million years ago and the determination of age in years from the colour effect is far from easy.

The third method is based upon the accumulation of *radiogenic helium* and was first used in 1909 when the age of a pre-Cambrian zircon was estimated to be 700 million years. This figure is a minimum one, since some of the helium may have escaped in the course of time. With the development in 1928 of a new technique

TABLE I

THE GEOLOGICAL TIME SCALE.

ERAS	SYSTEMS	TIME IN MILLIONS OF YEARS	LIFE	OROGENIES AND VULCANICITY	MAJOR GEOGRAPHICAL CHANGES
CENOZOIC TERTIARY	NEOGENE		ORIGIN OF MAN	ALPID	TEMPERATE & GLACIAL
	PALÆOGENE	50	RISE OF MAMMALS & MODERN FLORA.		SUB-TROPICAL SEAS WITH SHORT LAND PHASES.
MESOZOIC	CRETACEOUS	100	AGE OF AMMONITES AND REPTILES.		
	JURASSIC	150	BIRDS APPEAR IN JURASSIC TIMES.		
	TRIASSIC		MAMMALS APPEAR IN TRIASSIC TIMES.		TROPICAL DESERTS AND SEMI-ARID LANDS.
UPPER PALÆOZOIC	PERMIAN	200	MAMMAL-LIKE REPTILES OCCUR.		
	CARBONIFEROUS	250	AGE OF AMPHIBIANS & COAL MEASURE FORESTS. REPTILES APPEAR.	ALTAID	EQUATORIAL DELTA SWAMPS AND SEAS.
	DEVONIAN	300	AGE OF PRIMITIVE PLANTS & FISHES.	CALEDONID	TROPICAL DESERT LANDS AND DELTAS.
LOWER PALÆOZOIC	SILURIAN	350	PLACODERMS APPEAR.		
	ORDOVICIAN	400	ABUNDANT MARINE INVERTEBRATA. ECHINODERMATA, BRYOZOA AND AGNATHA APPEAR.	EOCALEDONID	WARM SEAS WITH MOUNTAINOUS COASTS AND ISLANDS.
	CAMBRIAN	450	FIRST APPEARANCE OF ABUNDANT LIFE (PROTOZOA, PORIFERA, BRACHIOPODA, ANNELIDA, MOLLUSCA, ARTHROPODA, ETC.) IN THE SEAS.		
		500			

enabling quantities of helium as small as 0·000001 ml. to be measured, the method was applied to rocks, all of which possess minute amounts of radioactive matter. Many were examined and their ages in years determined. The results were invalidated in 1939, when it was found that the constituent minerals of a rock give different values for its age. For example, the Palisade diabase was separated into its constituents—plagioclase, pyroxene and magnetite. The plagioclase gave an age of 36 million years, the pyroxene 103 million years and the magnetite 134 million years. This is due to the differing retentivities of the minerals. Magnetite retains the helium three times as well as the felspar.

Attempts are being made to rescue the method. Two assumptions are necessary, namely that all helium formed in magnetite is retained and that all the helium is derived from uranium and thorium. The age of the rock is then obtained by extracting the magnetite, cleaning it from adherent minerals and measuring the helium, uranium and thorium content. Aberrant results are sometimes given and confidence in the method has not yet been fully restored.

One use of radioactivity in determining the absolute ages of fossils is based on the counting of the radioactive disintegration of carbon 14 in charred bones. Certain disadvantages limit the application of the C 14 method. Large samples are necessary and there is always the possibility of contamination. Another serious drawback is that the method has a small time range (about 40,000 years) and is therefore more valuable to the prehistorian than to the palaeontologist.

VARVES AND TREE RINGS

Other methods of absolute dating of rocks and fossils exist which do not depend upon radioactivity. Sedimentary rocks may be dated by varve counting, a method which has been very successful in glaciated areas (Fig. 1). As an example, the Green River shales of Wyoming and Colorado, which are of Eocene Age, may be mentioned. Each layer in these shales consists of two laminae representing the sediment laid down in one year. The paired laminae constitute varves and average less than 0·006 of an inch in thickness. Since the Green River shales are 2600 feet thick, the time represented by them is approximately 6 million years.

Among plants, tree-ring counting may be used for dating purposes. It is based upon the annual growth-rings in wood. Usually, trees produce one ring per year and it is formed by the cambium which lies between the old wood and the bark. The ring sequence is counted along a radius and thickness variations plotted on co-ordinate paper. Such "skeleton plots" enable correlations to be made. Reliable dating of cultural phases of the south-western U.S.A. has been effected and a connexion established between tree growth, climate and cyclic changes in solar radiation.

By matching curves of past insolation, i.e. the effect of the sun's rays on the materials composing the surface

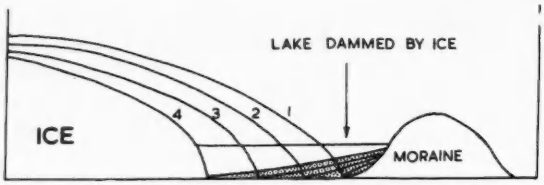

FIG. 1. This diagram illustrates the formation of annual varves (represented by stippled areas) during the retreat of ice from a moraine. Successive winter-halts of the ice are numbered 1, 2, 3 and 4. Each varve terminates at the line to which the ice receded in the particular year. (After Zeuner.)

of the earth, calculated by Milankovitch and Spitaler with geological evidence of glacial fluctuations, it has proved possible to infer absolute dates. The disadvantage of this method is that it is based upon theoretical considerations.

Various relative dating methods exist which do not depend upon the fossil succession and these must be mentioned.

Flint patination may be used as a check upon the age of a speciment inferred from its morphology alone and depends upon the alkalinity of the soil. It is far from reliable.

In archaeological research, palaeomagnetism can be used as a means of determining the age relation between a specimen and its containing deposit. It is based upon a comparison of the magnetic orientations of particles in pottery. By studying deposits with the object of inferring the climatic conditions at the time of their formation, it is occasionally possible to correlate them over wide areas. Tectonics can be important in correlation, since faulting and thrusting may occur over large tracts of land and serve as datum lines. Vulcanology, too, can play a part in correlating formations. Lava may vary in lithological character and be useful as a stratigraphical landmark.

In the last few years, great progress has been made in dating methods not yet mentioned. These will now be examined and some of the spectacular results indicated.

THE FLUORINE METHOD

In 1844, James Middleton read a paper to the Geological Society of London in which he announced his discovery that fossil bones and teeth absorb fluorine from the soil in which they have been buried. Consequently, the greater their antiquity, the more fluorine they will contain. Carnot, a French mineralogist, reaffirmed this principle in 1894 and analysed a number of fossil bones from various localities and geological horizons ranging from Palaeozoic to Recent. His results demonstrated the truth of the observation, but by averaging his figures he obscured the important fact that there is a wide variation in the fluorine content of bones of the same geological age from different localities.

The method was not revived until recent years. In 1947, H. J. Walls tested the fluorine content of a series of selected bone samples from the Kanjera-Kanam region of Kenya and was able to show that the method cannot be used in areas where fluorine is abundant or in places subject to tropical weathering where rapid and haphazard mineralisation can occur. In temperate regions, however, the progressive increase in fluorine content is gradual. By a process of irreversible ionic interchange, the element is fixed into the mineral substance of the bones or teeth, hydroxyapatite being converted to fluorapatite, thus:

$$Ca_{10}(PO_4)_6.(OH)_2 \rightarrow Ca_{10}(PO_4)_6.F_2.$$

Comparison of the fluorine content of fossil human skeletal material with that of animal remains in the same or nearby deposits sometimes enables estimates of relative antiquity to be made.

The method has been applied to the dating of the Swanscombe, Galley Hill, Fontéchevade and Saldanha skulls with the following results. The Swanscombe skull has been shown to be contemporaneous with the associated Acheulian hand-axe industry. It is the oldest known human cranium in Europe. The Galley Hill skeleton possesses a very low fluorine content and undoubtedly represents an intrusive burial. Investigation of the Fontéchevade skulls found below a stalagmitic sheet separating a flake-industry deposit called the Tayacian from the overlying Mousterian-Aurignacian complex, showed that they are probably of Tayacian Age, i.e. about 165,000 years old. They certainly belong to a later interglacial than the Swanscombe skull. In the case of the Saldanha skull, analysis indicates that it is contemporaneous with such extinct forms as Palaeoloxodon, Mesochoerus and Griquatherium.

The outstanding success of this method of relative dating, however, has been the exposure of the Piltdown hoax (see Table II). The first examination of the Piltdown specimens for analytical purposes was carried out in 1949 at a time when at least 20 mg. of bone were needed to ensure accurate results. Owing to the supposed uniqueness of the materials, only 5 mg. samples were available. The results showed that the Lower Pleistocene fossils at Piltdown contained 2% fluorine in contrast to the cranial fragments and mandible which contained from 0·1 to 0·4%. The teeth contained less than 0·1%, a figure which would not be impossible if they were of *Upper* Pleistocene Age. Weiner's suggestion that the mandible and canine tooth actually belong to a modern ape and were deliberately faked to simulate fossil specimens led to a critical study which produced great advances in technique. Between 1949 and 1953, more refined methods made the detection of minute quantities of fluorine possible and the subsequent finding of only 0·03% fluorine in the mandible represents a triumph of these most recent chemical techniques.

THE NITROGEN METHOD

As a result of chemical studies of bones from early occupation sites in North America, Cook and Heizer were able to show in 1947 that bones preserved under

the same conditions lost the nitrogen contained in their protein (ossein) at an almost uniformly declining rate. Organic matter is rapidly lost immediately after interment which restricts the use of the nitrogen method to relatively recent specimens. In such cases, it is a useful supplement to the fluorine method and can be utilised when the specimens are too recent to come within the effective range of the latter.

Analysis of the Piltdown cranium showed that it contains only slightly less nitrogen than Neolithic bones, thus suggesting a late Upper Pleistocene Age. On the other hand, the high nitrogen content of the mandible and teeth confirms the evidence from fluorine analysis that they are much more recent.

It must be remembered that low nitrogen content alone does not indicate antiquity, since if a bone is exposed to weathering, the nitrogen disappears rapidly. This is the explanation of a discrepancy between the fluorine and nitrogen contents of the Piltdown 'II' occipital fragments. Here, the former is low, suggesting a recent origin and the latter also is low, suggesting an ancient origin.

RADIOACTIVITY AND PILTDOWN MAN

Recent work by Bowie and Davidson has shown that fossil bones and teeth adsorb uranium from percolating groundwater. Their radioactivity depends on age, permeability of the enclosing sediment and the uranium content of the water. Usually, the higher the uranium content, the older the specimen concerned. Measurement is carried out by using a Geiger counter within a massive lead chamber. Examination of the primate remains from Piltdown has demonstrated that all have a much lower radioactivity than that shown by a large number of bones of Pleistocene Age derived from some other gravel beds. The inference is that the remains are probably of post-Pleistocene Age and hence of later date than the gravels from which they were supposed to derive. The advantage of this method of measuring the age of fossil bones is that none of the material is consumed.

Specimen		% F	% N
Piltdown I	cranium	0·1	1·4
	mandible	0·03	3·9
	canine	0·03	5·1
	molar	0·04	4·3
Piltdown II	occipital	0·03	0·6
	molar	0·01	4·2
Upper Pleistocene bones (minimum)		0·1	0·7
Neolithic bones			1·9
Fresh bones			4·1
teeth		0·06	

TABLE II.—RESULTS OF ANALYSES OF FLUORINE AND NITROGEN CONTENTS OF PILTDOWN SPECIMENS AND OTHER MATERIAL MADE DURING 1953

THE SULPHUR METHOD

This method gives some indication of when photosynthesis began and hence an approximate idea of the date of the commencement of life on the planet. It depends upon the fact that sulphur consists of two isotopes, S^{32} and S^{34}. The ratio of S^{32} to S^{34} in early pre-Cambrian sulphides and sulphates is about 22:1. In sea-water sulphate it is 21:8. About 800 million years ago, a process began which gradually increased the amount of S^{32} in sulphides and diminished it in sulphates and the only known process which could cause this is the oxidation of sulphur or H_2S to sulphate by bacteria and its subsequent reduction by plants and other bacteria. In 1953, Thode, Macnamara and Fleming suggested that sulphur oxidising bacteria originated 800 million years ago, an event which "predates the beginning of large-scale photosynthesis". Their graphs indicate that the oxygen content of the atmosphere has probably increased a good deal since the Cambrian. It appears likely that, if their views are correct, life is less than 1000 million years old.

On the other hand, more recent evidence from Canada appears to increase this figure appreciably and casts doubt on the accuracy of the sulphur method. Two kinds of algae, two of fungi and an organism supposed to be a calcareous flagellate have been recorded by Barghoorn and Tyler from a chert deposit below an iron-ore bed on the northern shore of Lake Superior, Ontario. The iron-ore bed is 1300 million years old according to Hurley and the fossils are reputed to be 2000 million years old.

In view of this, MacGregor's 1940 record of algae from cherts and pillow lavas of the Bulawayan system in S. Africa dated as 2600 million years old—a figure endorsed by Holmes—appears reasonable and if true, represents the oldest life yet discovered on the planet.

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THE BOOKSHELF

The Laws of Nature

By R. E. Peierls (*London, Allen & Unwin, 1955, 284 pp., 21s.*)

As popular books on science go, Prof. Peierls' exposition of modern physics for the non-specialist reader certainly presents an interesting departure from the usual pattern. It is true that the popularisation of science ranges over a wide variety of approaches from "science fiction" to the efforts of responsible scientists at making their subject intelligible to the general reader. However, even the latter usually confine themselves to recording and correlating the facts and to telling the story, thereby asking the reader to take their conclusions on trust. Beyond that, there is only the textbook. *The Laws of Nature* is a remarkable book which in many ways fills the gap between the two. In spite of the absence of mathematics and of technical terms, the author clearly sets out not only to interpret but to *teach* physics. To try to do this within the restrictions of simple language, is no mean task in itself, but the outstanding feature of the book is the ingenious choice and grouping of the subject matter. Here an effort has been made to take the reader from the basic observations by a series of proved conclusions to the limits of our present knowledge. The writing of this book cannot have been easy, but probably the author found it a delightful task.

The three opening chapters deal in turn with the classical laws of mechanics, electro-magnetism and light. In these it is the economy and not the amount of information which is worthy of note. The great body of existing classical knowledge on these subjects is rigidly excluded except where it serves as a basis for the later discussions of relativity and quantum mechanics. The basic concepts, on the other hand, are treated with great care and clarity. The reader is thus thoroughly prepared for his task, but with a minimum of strain on his memory. The significance of angular momentum, the interrelation of magnetic and electric field and the laws of wave motion are explained in simple and unambiguous terms.

The following two chapters deal with the atomistic structure and with the general aspect of aggregate matter. The latter is possibly the weakest chapter in this excellent book. Regarding the laws of nature in general, the author seems to have concentrated on those of particle physics (including photons) rather than on those of statistical mechanics. However, this may have been a self-imposed limitation in order to keep the scope of the book within reasonable bounds. In any case, the only harm done is to give the non-physicist reader a slightly too one-sided picture of the problems of modern physics.

The next three chapters on relativity, quantum mechanics and its application to the single atom as well as to the solid state present a brilliant account of the established progress of physics in the last half century. Relativity is usually discussed in connexion with its cosmological significance which clearly lies outside the scope of this book, and the author has therefore placed the emphasis on deriving the law of equivalence of mass and energy, and on the behaviour of fast-moving particles, both of which have an important bearing on what is said in the following chapters. The quantum principle is introduced, as it was deduced historically, through the deviation of radiation intensity from the law of equipartition. Then the basis of wave mechanics and the uncertainty principle are dealt with. The quantum laws are now applied to atomic structure and the exclusion principle is added, leading to the concept of spin and its quantisation and to the electronic shell model. The chapter ends with applications of quantum physics to molecular binding and to the solid state such as degeneracy of the metal electrons, quantisation of the thermal vibrations and the tunnel effect in cold emission.

The front line of modern research is reached in the three final chapters, dealing with high-speed electrons, nuclear structure and the new particles respectively. The first in particular is likely to present somewhat difficult reading which, however, is rewarded by getting the Lamb shift and self-energy explained. Since a good deal has been written about the nucleus, mesons and cosmic ray research, the last two chapters will be familiar ground to many readers who can relax here and enjoy the author's skill of presentation to the full.

The pleasing thing about this book is that one can learn such a lot from it. It can certainly be read with advantage by all physicists. The student will get a clear and crisp survey of the field before him, the research worker and schoolmaster will be well informed about recent progress and the professor will enjoy and take note of the elegant technique employed by the author in teaching a difficult subject. There are clearly many others to whom the book can be recommended. The blurb says that an engineer, a general practitioner or a philosopher can read it—but they would all have to put some concentrated effort into doing so. This is a beautifully clear book for which no dictionary or work of reference is required, but it would be foolish to suggest that it is easy to read. To appreciate it fully, one has to turn back occasionally and re-read what has been said in the earlier chapters. However, in the end one will have learned a good deal about modern physics and one's newly gained knowledge will be remarkably sound.

For one purpose the book will be quite invaluable, and that is in teaching adult education classes in physics. In a recent discussion in the columns of DISCOVERY on adult education in science the great need for books of this kind was stressed. I then drew attention to the unique opportunity of teaching modern physics without the need of wading through the usual textbook stuff. Prof. Peierls has now provided one excellent guide which will be of the greatest help to the teachers of these classes and will be thoroughly enjoyed by them as well as by their pupils. Moreover, the book is excellent value for money. K. MENDELSSOHN

Introductory Applied Physics

By N. C. Harris and E. M. Hemmerling (*New York and London, McGraw-Hill, 1955, 715 pp., 50s. 6d.*)

Physics for Our Times

By W. G. Marburger and C. W. Hoffman (*New York and London, McGraw-Hill, 1955, 559 pp., 34s.*)

These two works are conveniently discussed together as they belong to the same *genre* of books, which aim to introduce the student to physics by the easy path and which use copious illustrations and a colloquial style. The authors of *Introductory Applied Physics* have made a special effort to fit vocabulary and style to the verbal ability of U.S. students in "technical majors"; the tone of *Physics for Our Times* may be judged from the authors' approach to their readers in the introduction entitled "Physics and You". The mathematics in both books do not involve more than simple algebra, and there is the usual collection of quiz questions which are such a useful feature of American texts.

The first book is the more business-like in its coverage of the familiar sequence of topics: Properties of Matter, Work and Energy, Heat, Wave Motion, Light and Optics, Magnetism and Electricity, and finally, of course, Atomic Energy. The plan of the other book is similar, but the treatment is made more "popular" by the use of such headings as "Sorting Molecules with a Sieve" and little comic drawings at the head of each chapter.

In attempting to assess the value of these books to the British sixth-former or other student one must be satisfied that they do in fact present the subject in an acceptable way and in such a manner that the reader would benefit from owning the book.

Judged by these questions, one would be inclined to prefer *Introductory Physics* to the brighter *Physics for Our Times*. The latter would have an appeal, not so much to the student but to the intelligent adult whose scientific

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education has been neglected and who would read it with profit. If a school librarian decided to buy *Introductory Physics* the money would not be wasted, but the conservative teacher would probably cling to the conventional texts on which British physics teaching has been founded. This is to be deprecated, as the authors of the book have shown that the subject can be presented in an attractive manner, and they set an example to British authors in the art of illustrating the text. There is also the question of fundamental differences in approach to scientific education.

Both books are magnificently bound and produced (*Physics for Our Times* has eight coloured plates) and considering the high prices which are asked for inferior products, they are worth the figure asked. G. P.

British Mosses and Liverworts

By É. V. Watson (*London, Cambridge University Press, 1955, 419 pp., 45s.*)

Britain has lacked a book on bryophytes which could be put into the hands of a beginner with any confidence that it would lead him to the correct identification of his plants. This book is evidently intended to supply this need.

It is perhaps inevitable that the book should be compared with the standard textbooks: Dixon's *The Student's Handbook of British Mosses* and MacVicar's *The Student's Handbook of British Hepatics*. These books have long been, and are likely to be for some time, the indispensable handbooks of the advanced student of the group. To justify its existence, therefore, the new book should have features which set it apart from these, in its own field, as especially useful to the beginner.

An admirable feature of Dr. Watson's book is the word-picture with which each description begins, giving an outline of the salient features for recognition and a clear statement of its habitat; nothing similar is provided in the older books. The illustrations, including the useful habit drawings, should be most helpful as compared with the rather stylised drawings which are frequently found in books on bryophytes. The ecological notes are more extensive than is usual.

Another excellent feature is the field key, included in a special pocket at the end of the book, though only use can show how far it works. It has been criticised for its use of the nerve, a character often difficult to make out in the field even with a good lens. The other key, using microscopic characters, should also be an improvement on those in the older books, though it may be regretted that the early separation of *Andreaea*, which always proves a stumbling-block to beginners in the use of the key in Dixon's book, is retained.

The photographs are admirable, though they are too few to be considered aids to identification. They do give, however, an impression of the main variations in habit.

While the book will undoubtedly enable students to obtain a good acquaintance with the common species (especially those of southern England) it will probably not be long before difficulties are encountered. Dr. Watson has partly allowed for this in his short descriptions of "additional species" and "related species". These should in many cases (e.g. *Ulota bruchii*) be adequate for determination but in others their usefulness is doubtful. Thus *Ditrichum cylindricum* is scarcely likely to be recognisable from its description (though it is, of course, included in the key), while the habitat given ("woodland rides") will scarcely help those who find it in arable fields which are its most usual habitat. Some of the omitted species, also, are common in certain areas, especially north-west Scotland, where one soon encounters *Mastigophora woodsii* and *Jamesoniella carringtonii*. This is perhaps not a serious defect, provided one is aware of it. The complete omission, however, of such species as *Campylium sommerfeltii* (which is not rare in the Chilterns, for example) may prove misleading.

The habitat lists at the end of the book, though admirable in intention, may mislead both by what is included and by what is excluded.

The book can be strongly recommended to the beginner and to the non-specialist and should stimulate further the growing interest in bryophytes. The price is very reasonable by present-day standards. E. F. WARBURG

If You Must Write

By W. H. Johnson (*London, Hutchinson, 2nd edn., 1955, 98 pp., 4s.*)

Mr. Johnson (whose book draws heavily on the author's experiences as an editor of scientific and technical books) starts out with the idea that words are meant to convey meaning from one person to another. To judge from the writing of the average scientific report, this idea is not as startlingly self-evident as it appears. Mr. Johnson, in fact, quotes a remark made by a very important person at Farnborough on a report. "This report is no good. Anyone can understand it." The V.I.P. was using good, concise English but he probably did not appreciate what he was doing.

There have been plenty of books on English and how to write it, which do not seem to check the flood of mediocre writing. It will be a pity if Mr. Johnson's excellent book produces as little obvious result as the others. The fact that this is the second edition is cheering. It means, perhaps, that more and more people are realising that the writing of clear English is not as easy as it sounds.

Part of the trouble arises because the equipment for writing is so simple. All anyone needs is some paper and a pen, and few activities demand so little kit to start with. Nearly everyone can construct a sentence and therefore imagines he can write. Generally he is wrong. Nine times out of ten what he will produce is a string of sentences, and there is much more in writing than stringing sentences together.

I cannot say anything about other professional men but I know that scientists are too ready to assume that they know all about how to write without having written anything that a hard-headed editor or publisher has paid them for. Unfamiliarity breeds contempt. It is obviously impossible for every scientist to command the brevity and clarity of Bertrand Russell, for example, but at least he ought to know enough about his own language to be able to write something passable, if not distinguished. The most frequent sin is to be pompous and verbose. One actual example, among hundreds I have come across, is the use of the phrase "gained access to oviposit" when it means no more than "came in to lay eggs". I think that this is the result of people trying to write "up" to some sort of vague standard of "Good English" in which the longer the words the more important and weightier the sense is supposed to be. In fact, the sense can get lost and then the reader becomes bored. The first requisite for good English is that it must convey sense. (The sense must be worth conveying, naturally. I once read an impression of a visit to India by a scientist whose opening sentence read, "The first impression one has of Calcutta is that it is full of Indians.")

This brings us full circle back to Mr. Johnson's book. The first half discusses crimes against the language, and there is a fine "Black Museum" of exhibits scattered throughout the chapters. It includes a long and useful list of words that are commonly misused. This is salutary reading. (How many people can give the correct meaning of "transpire", for instance?)

Mr. Johnson then discusses the business of offering a manuscript, preparing it for the Press and dealing with editors. The most elementary mistakes are always being made by authors. There is nothing more maddening to an editor than to receive a typescript typed with single spacing on both sides of the page; or again the typescript arrives with the illustrations inserted in it. Mr. Johnson goes patiently over these errors and explains why they should not be committed, with impressive detail and good temper.

The book, to use a cliché, should be on every would-be writer's shelf. At intervals of six months it should be taken out and read again. It would be an extraordinarily competent person who did not find that he had slipped back since the last time he read it.

The great thing about the book is

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that the reader is left with the conclusion that it is difficult to write good English and it takes time, skill and appreciation to learn how to do it, but that it is worth while doing it.

On one occasion arrangements were being made for a scientific report to be rewritten by a professional writer. A certain fee was suggested, and across the memorandum proposing this a Civil Servant wrote, "This seems a very high price to pay for two sheets of foolscap." There was a man who needed Mr. Johnson's book. R. H.

Discoveries and Inventions of the Twentieth Century

By J. G. Crowther (*London, Routledge & Kegan Paul, 1955, 432 pp., 129 line drawings, 64 plates, 30s.*)

This is a revised edition of the book by Edward Cressy which first appeared in 1914, and was followed by a second and a third edition in 1922 and 1930 respectively. The quarter-century that has elapsed since the latter year, while by no means rendering obsolete all of the material assembled by Cressy, has naturally added much to the total of discoveries and inventions, particularly in the fields of engineering, applied chemistry and electronics. Mr. Crowther, although following in broad outline the plan of the original work, beginning with water power and ending with radioactivity, has incorporated considerable information on the latest developments, thus producing a comprehensive and up-to-date account of technological progress during the past fifty-five years.

According to the preface to the first edition (part of which is reprinted here), "the book is written for those, young and old, who wish to have a non-technical account of the great scientific and material triumphs which man has achieved and is achieving in their own day; and it seemed desirable to give the first place to those theories, facts and accomplishments which are now exercising the greatest influence upon human life". Its title is, in fact, accurately descriptive of its contents, and it compresses most usefully into a single volume a wide variety of subjects. One rather surprising omission is the absence of any mention of electronic computers, already so far developed as to be of high practical importance, and of more immediate influence upon human life than radio-astronomy, which Mr. Crowther does briefly describe. However, a halt must be called somewhere; and it might, perhaps, be urged that digression into scientific instruments would expand the book beyond a reasonable compass. As it stands it is a sound compendium of its kind, and many a layman of a mechanical turn of mind will delight in it. E. N. PARKER

Principles of Biochemistry

By A. White, P. Handler, E. L. Smith and De W. Stetten. *New York and London, McGraw-Hill, 1954 1117 pp., 112s. 6d.*)

The rate of progress of biochemistry is such that each succeeding year makes the compilation of a comprehensive book progressively more difficult and already the task is probably beyond the capacity of any single individual. In the present volume four authors have divided the subjects among themselves and have afterwards edited and co-ordinated their efforts. This method has resulted in a closely knit text which covers much of the chemical background of biochemistry as well as intermediary metabolism, the biochemistry of body fluids, of specialised mammalian tissues, of endocrine glands and of vitamins.

The authors state that their book "attempts to present an introduction to biochemistry for medical students and others who are concerned primarily with mammalian biochemistry", but this book is much more than an "introduction" and might well be found rather indigestible by the average

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medical students in this country. Perhaps his counterpart in the U.S.A. has a stronger stomach; he certainly must have a longer purse if he can afford nearly £6 for a textbook of biochemistry. In the reviewer's opinion this book will be useful to the student who proposes to specialise in biochemistry, or to his teacher. As might be expected in a textbook designed for medical students adequate attention is given to the interpretation of disease in biochemical terms.

Individual chapters are clearly written and packed with information but one is inclined to wonder whether at times the authors have included too much and at other times too little. The medical student for example will make little of such remarks as (p. 832) "since resonance between the porphyrin rings is no longer possible, mesobilirubinogen is colorless" while the more serious student of biochemistry will find the absence of references disconcerting. The authors have provided at the end of each chapter a list of review articles, books and papers for further reading which should be valuable, but even with this help the student might find it difficult to check or to amplify some undocumented and isolated statements such as (p. 846) "interest centres on the lymphocytes as cells of importance in antibody synthesis".

It is not unduly difficult to collect together the facts which go to make a textbook but it is difficult to arrange those facts in an interesting and readily digestible fashion. In this respect some chapters in the present volume are admirable; the section on nutrition, for example, achieves a nice balance between the historical, the practical and the academic but in other places one has the impression that the subject has no history or that knowledge of the development of the field is thought to be of little educative value. The student might benefit also from a greater emphasis on the experimental basis of our biochemical beliefs, since our conception of the truth changes while our methods of arriving at the truth remain largely unchanged. It might be argued that in a textbook which already extends to 1100 pages the additional information would make the book too large, but perhaps by weeding out inessential detail more space might be found in a second edition for a less strictly factual presentation.

On the whole, errors are notable by their absence though occasionally a statement is made in more dogmatic form than is justified by the available evidence. The text is amply illustrated by formulae and diagrams of a high standard. On p. 135 there is an unfortunate lapse in proof reading where a CH_2 group has been omitted from a whole series of formulae. Unfortunately also, ^{11}C does not have a half life of 20·5 months but of 20·5 minutes.

T. S. WORK

Life, The Great Adventure

By Jean Rostand (*London, Hutchinson's Scientific and Technical Publications, 1955, 258 pp., 12s. 6d.*)

The basis of this book (originally published in France) was a series of broadcasts in which a well-known French biologist answered some searching questions put to him by a journalist, Paul Bodin, who has written several books of scientific interest. The questions were very big ones—of the nature of What is man? Where did man come from? Where is he going?—and the answers cover a great deal of interesting ground. All kinds of incidental matters are discussed, as for instance human twins, changes of sex, the long-term effects of using antibiotics, cancer, the freezing of mammals and the application of this technique in surgery, while the subject of longevity is given a whole chapter ("Man Could Live to be a Hundred and Twenty Years Old"). This is a book that will appeal to all who enjoy listening to radio "Brains Trusts". The translation is by Alan Houghton Brodrick.

FAR AND NEAR

Night Sky in September

The Moon.—Full moon occurs on September 2d 07h 59m U.T., and new moon on September 16d 06h 19m. The following conjunctions with the moon take place:

September			
14d 00h	Jupiter in conjunction with the moon	Jupiter	5°N.
18d 12h	Mercury	„ Mercury	2°N.
20d 16h	Saturn	„ Saturn	5°N.

In addition to these conjunctions with the Moon, Mercury is in conjunction with Spica on September 21d 02h, Mercury 1°S.

The Planets.—Mercury is too close to the sun for observation during September. *Venus*, in superior conjunction on September 1, is also too close to the sun for observation. *Mars* rises about 4h 40m throughout the month. Early in September it is very close to ρ Leonis from which it has an eastward movement, and about September 24 it is a little S. of σ Leonis. At the end of the month it is E. of β Virginis, moving into the Constellation Virgo early in October. *Jupiter* rises at 3h 15m, 2h 35m, and 1h 55m, on September 1, 15, and 30, respectively. Its slow motion from Cancer into Leo can be noticed but it is not close to any bright star during the month.

Saturn sets at 21h, 20h 10m, 19h 10m, at the beginning, middle, and end of the month, respectively. At the beginning of the month it is a little E. of αLibrae but its easterly motion takes it almost exactly midway between α and γLibrae at the end of the month. Though it is only a little brighter than a 1st magnitude star it is easily recognised; if there should be any doubt, its rings will be seen with binoculars or even a hand telescope.

Autumnal equinox is on September 23d 20h; on this date the sun's declination is zero and days and nights all over the world are equal, each being 12 hours.

National Diplomas in Technology

An outline sketch of the new scheme for awarding National Diplomas in Technology was given to the House of Commons by the Minister of Education during the debate on the shortage of scientific and technical manpower on July 21. Sir David Eccles was the first Government spokesman on this occasion, and the debate concluded with a statement by the Financial Secretary to the Treasury, who explained plans for expanding the provision of university education. This "division of labour" was a reflection of the fact that "Government responsibility for technical education in England and Wales is shared between the Chancellor of the Exchequer, who is concerned with the universities, and the Minister of Education, who is responsible for the technical colleges", to quote *The Times* educational correspondent.

Sir David said that development of the scheme, which will involve certain approved technical colleges, will make it necessary to distinguish two kinds of colleges. On the one hand there are the purely local colleges which offer day release and evening courses and full-time courses leading to such awards as the Ordinary National Certificate and Diploma. Then there will be the regional colleges giving approved advanced courses in technology. A council, whose first chairman is Lord Hives of Rolls-Royce, is being set up, and Sir David said that this new body will be responsible for approving the syllabuses, the conditions of teaching, the qualifications of the teachers, and the examinations to be held in these regional colleges, as well as the grant of the national award to students who satisfy the examiners.

The Minister spoke of the scheme as having been recommended by the National Advisory Council for Education for Industry and Commerce (whose chairman is Sir Ronald Weeks), and he

gave the impression that this organisation had protected the scheme from being extinguished by its critics. The germ of the scheme can be found in the Advisory Council's draft report which gave rise to the Government White Paper on technological education published in the autumn of 1951 (see DISCOVERY, November 1951, pp. 335–7). But the original draft report and the White Paper both contain a very muddled collection of proposals, and it certainly looks as though the criticisms they received from such bodies as the engineering institutions and from a wide range of influential journals performed a useful function; at the very least the critics should be credited with having helped to separate the chaff from the grain. If the National Advisory Council deserves credit for proposing a scheme that now looks practicable, then the critics are certainly entitled to some credit for making the Council revise their first thoughts on this matter. (The announcement of the scheme was welcomed by the presidents of the three biggest engineering institutions—Electrical, Mechanical and Civil—in their joint letter to *The Times* of July 20, 1955, as a piece of "positive action which may alleviate" the serious shortage of technologists. But this same letter indicated that the institutions do not entirely agree with the proposed scheme, and are in favour of the concentration of "national resources within a small number of colleges of technology chosen on the basis of the comprehensiveness of their scientific and technological facilities and potentialities, and not on a capacity to deal with a single technology only.")

Rather tantalisingly, Sir David Eccles was unable to provide the House with complete details of the scheme. These are still to be worked out, but he promised a full statement before Christmas. The Minister did however make it clear that these diploma courses would be designed as sandwich courses for student apprentices who would work six months in industry and six months in a college for a period of four or five years. He said he fully expected that the content of, say, the mathematics, science and engineering subjects would not differ strikingly from that of a university syllabus. "The students will have time for basic studies in science and related technologies, and a measure of liberal education."

Several members pressed the Minister for more information, and one questioner did elicit the following significant remark from him: "I hope that the regional colleges will divest themselves of the lower-grade work, which will be taken up by the group of local technical colleges which will serve as satellites, one might say, around the regional college."

Often when such matters are being discussed there is a tendency for the words "technologist" and "technicians" to be used carelessly, and sometimes even as synonyms. It was noteworthy that the members who took part in this debate seemed to be taking special pains to avoid such confusion. One of them, Sir Hugh Linstead, did in fact take the trouble to give a clear definition of the two terms: "The technologist is the man with knowledge of the basic sciences which he can apply to new problems and processes, the man who does the research work. The technician is the man who takes the results of that work and applies them; he may not invent new techniques and machines but he applies new techniques in improving existing processes and machines. The craftsman is the man who looks after the machines."

The same member asked some pertinent questions about the supply of teachers for the new technological diploma courses. He recalled that originally (December 1954) the Minister had said that some thirty colleges would ultimately become advanced technological regional colleges. If the diploma was to be of degree level and only fifteen colleges were to take on this work it would be an almost insuperable problem to find the suitable senior staff to teach the supporting sciences—chemistry, physics and probably mathematics—in addition to the teachers of the technologies. He suggested that Lord Hives's Council might find it best to concentrate first on half a dozen colleges.

Deferment of Science Teachers

In this debate few members did more than mention the shortage of science masters. An exception was Mr. Arthur Skeffington. Among other things he did a useful service in drawing attention to the existence of the report prepared by the Appleton committee on the supply of science and mathematics teachers in Scotland. This (Cmd. 9419, price 1*s.* 6*d.*) has not attracted all the attention it deserves as one of the most thorough studies of the problem yet made. It is true that some of the information in it, and some of its recommendations, apply only to Scotland, but as a whole it is very relevant to the national problem and should be closely read south of the Border. The causes of the science master shortage are very clearly set out. Among the remedies the Appleton committee recommended, three are selected for special mention as likely to yield quick results. They are:

(1) The deferment from National Service of specialist teachers of mathematics and science (described as "the only sure means of getting more teachers quickly").

(2) The payment of both salary and pension to retired teachers of mathematics and science who return to service.

(3) The payment without the imposition of a means test, of a sum of the order of £250 to mathematics and science graduates for maintenance during their year of teacher training would remove immediately a strong deterrent to recruitment.

These measures the committee regards as exceptional, and ought not to be continued when the staffing emergency is over.

* * *

On July 28 the Minister of Labour, in a written reply to a question from an M.P., stated that as from next year favourable consideration will be given to indefinite deferment of first and second class honours graduates in science and mathematics who take up teaching in a school which is either maintained or aided out of public funds or which the Secretary of State for Scotland and the Minister of Education consider should be similarly treated for this purpose. As long ago as August 1952 the proposal was made in the columns of DISCOVERY that science teaching should be treated as an alternative form of national service (see "Science in the Schools" by Dr. Eric James of Manchester Grammar School, DISCOVERY, Vol. 13, pp. 254–5).

Atomic News

At a meeting of Nobel prizewinners at Lindan on July 12, PROF. WERNER HEISENBERG talked about German plant for atomic research. According to *The Times* correspondent, Prof. Heisenberg, who is expected to direct the German atomic station, said it was unfortunate that its planning should be obscured by uncertainty about the place where it was to be situated. A grave mistake had been made in failing to decide this two years ago. The decision between Munich and Karlsruhe is still open. Lately plans had even made their appearance for the division of the station, putting the scientific part of the work at Munich and the technical part at Karlsruhe. This was contrary to the whole sense of the enterprise, in his view. At the most, political reasons might justify putting the production of plutonium and the enrichment process in a separate place from the reactor station. But the best thing for the enterprise itself would be to put it all in one place.

Prof. Heisenberg put the probable cost of the German station at about 28 million marks, of which the reactor would take 17 million.

On August 2 *The Times* correspondent in Bonn reported that the Federal Government has decided on a site near Karlsruhe for West Germany's first atomic pile.

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The first atomic reactor designed exclusively for medical research and treatment will be built for the University of California at the Los Angles medical centre under a contract with the Atomic Energy Commission, Mr. Strauss, chairman of the commission, has announced.

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